The bumpy road to effective hamstring injury prevention in male amateur soccer players

Risk factors, plyometric training, adherence, return-to-play and prognostic factors

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Met vallen en opstaan naar effectieve hamstringblessurepreventie in het mannelijke amateurvoetbal

Risicofactoren, plyometrie, adherentie, sporthervatting en prognostische factoren

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"Be a free thinker and don't accept everything you hear as truth. Be critical and evaluate what you believe in."

Aristoteles

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1

General Introduction

GENERAL INTRODUCTION

Incidence and severity of hamstring injuries

In the Netherlands, around 1.4 million soccer injuries are reported annually[1]. Around 17% of these injuries are hamstring muscle injuries, which results in roughly 238000 hamstring injuries per year[2,3]. With these numbers, the hamstring injury is the most common muscle injury in soccer[2,3]. These hamstring injuries have a mean absence of sports of more than 28 days and high recurrence rates of 12-33%[2–6].

Anatomy

The complex bi-articular nature of the hamstring muscle might be one of the reasons of the high incidence (Figure 1). The hamstring muscle consists of three separate muscles located at the posterior side of the thigh: M. Biceps Femoris (consisting of the Biceps Femoris long head (BFlh) and the Biceps Femoris short head (BFsh), the Semitendinosus (ST) and the semimembranosus (SM). The BFlh, ST and SM originate from the ischial tuberosity, pass the posterior side of the thigh and cross the knee[7]. The BFsh originates from three anatomical locations, the linea aspera of the femur, the upper two-third of the lateral supracondylar line and the lateral intermuscular septum[8]. The BFlh and BFsh insert at the proximal fibula and lateral side of the tibia surface. The ST contributes to the pes anserinus and inserts at the medial surface of the tibia. The SM inserts at the posterior side of the tibia condyle, the popliteal fascia and the oblique popliteal ligament[9].

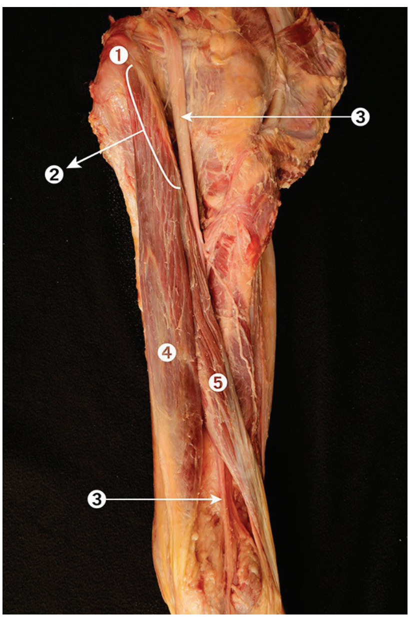

Figure 1. *Hamstring anatomy, rear view. Adopted from Stepién et al., (2019)10. (1) Ischial tuberosity; (2) conjoined tendon of the semitendinosus and the long head of the biceps femoris; (3) sciatic nerve; (4) semitendinosus muscle; (5) long head of the biceps femoris muscle*

Functional anatomy

The hamstring muscle complex (BFlh, SM, ST) is a bi-articular muscle group which operate as a hip extensor and knee flexor. The BFsh is a mono-articular muscle which operates only as a knee flexor. Of the three muscles within the hamstring muscle complex, the biceps femoris muscle is more frequently injured than the semimembranosus and semitendinosus muscle[4,6,11].

The major function of the hamstring muscle group are extension of the hip and flexion of the knee. The hamstring muscle group has additional functions as well[12]. The biceps femoris is connected directly to the ischial tuberosity, but in some cases it is directly linked to the sacro-tuberous ligament[13]. This ischial tuberosity is a central site on which the biceps femoris, semitendinosus, semimembranosus, gluteus maximus, piriformis and lumbar multifidis attach. This conjoint attachment plays a key role in force transmission from the spine to the lower extremity[14]. The assisting function of the hamstrings over the sacro-iliac joint and the lumbar spine is hypothetically essential in sprinting. During sprinting the force transmission from the spine to lower extremity, from the abdominal muscles, gluteal muscles to the hamstring muscles need to be optimal. The sequence of activation of these muscles is therefore related to hamstring injuries[15,16]. Additionally, the relation between the hamstring muscles and the lumbar spine underlines the thought of core-stability as another proposed risk factor[17]

Injury mechanism

The complex bi-articular anatomy of the hamstring muscle, their function over the hip and knee and assisting function over the sacro-iliac joint and lumbar spine, results in two types of hamstring injuries, the sprint-type and stretching type hamstring injury[11,18]. The most common hamstring injury type in soccer is the sprint-type hamstring injury. While the slow-stretching type hamstring injury affects the Semimembranosus, quadratus femoris or adductor magnus and is located closer to the ischial tuberosity, the sprint-type hamstring injury mostly affects the BFlh[11,18,19].

The sprint-type hamstring injury mostly occurs during the late swing phase[20]. During this phase the hamstring contracts eccentrically to decelerate the hip flexion and knee extension, than isometrically keeps that position, followed by a quick concentric contraction to accelerate the hip extension and knee flexion for an efficient and powerful next step in the sprint[4,21–23].

During the late swing phase, the BFlh stretches the most and receives the largest load. Therefore, the eccentric contraction received a lot of attention in the past years. However, it is also proposed that the complex intramuscular coordination patterns of the hamstring muscle group affects the amount of stress on the BFlh[24]. Therefore, the view in research is widened recently and it seems that timing and amplitude of activation of glutes and core musculature are important as well[25].

Risk factors

Assessment of risk factors for health related issues has a long tradition. In 1974, Rothman already stated that in medicine not one factor is sufficient to cause a disease[26]. In that sense, disease does not differ from injury occurrence[17,27–29].

An injury risk model was first developed in 1994 and further modified in 2007 (Figure 2)[30,31]. The recursive injury model describes the relation between intrinsic risk factors, extrinsic risk factors and inciting events with injury. All intrinsic and extrinsic risk factors interact with each other. A change in one of those factors influences the others. The recursive nature of injury describes the possibility of altered impact of risk factors by a change in one or more risk factors[31]. This recursive nature also plays a role after return to play following hamstring injury[31].

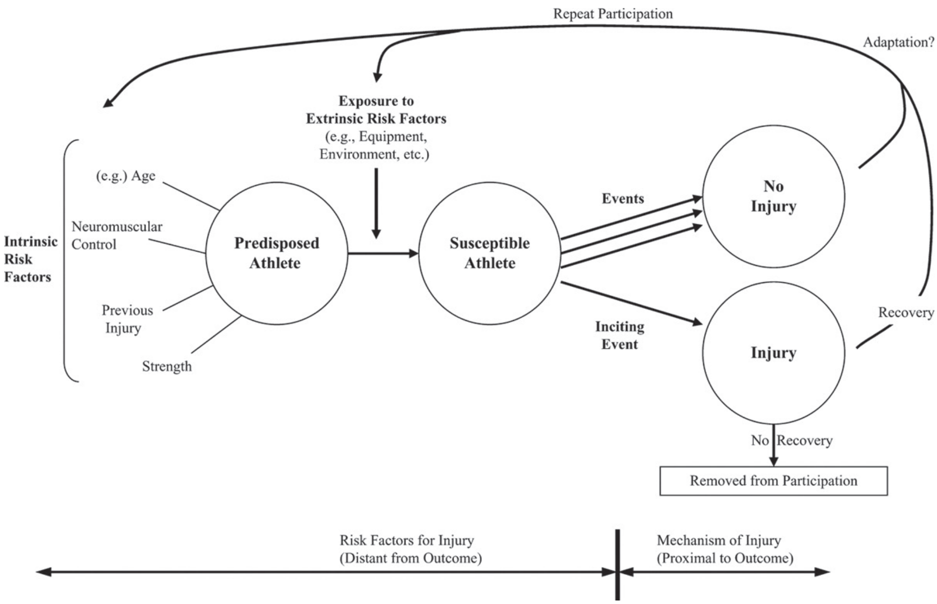

Figure 2. *A dynamic model of etiology in sports injury from Meeuwisse et al.*[31]

Reported risk factors are mostly divided in intrinsic and extrinsic risk factors. The intrinsic risk factors consist of age, gender, length, ethnicity and previous injury[32–34], but also strength imbalances, flexibility, fatigue and load[35–38]. The extrinsic factors consist of all factors that are outside of the player: Field conditions, weather conditions and timing in competition for instance[33,34].

Within the intrinsic and extrinsic risk factors, modifiable and non-modifiable factors can be distinguished. Modifiable factors are for example strength and flexibility which can be influenced by training. Unfortunately, there is currently only one evident risk factor for hamstring injuries, a previous hamstring injury, which is non-modifiable[33,39].

It is assumed that hamstring injuries have a large variety of causes and are multifactorial (figure 3). Based on the injury mechanism, players with for instance eccentric strength deficits and hamstring flexibility deficits are at higher risk for hamstring injury. additionally, in contrast with elite soccer players, amateur soccer players are not only practicing their sport but also have to work or study during the day. The different loads in daily jobs, travelling time and playing other types of sport on top of playing soccer might be considered as intrinsic risk factors in amateur soccer players. Therefore, we investigated the association between off-field activities and hamstring injuries in **chapter 2**.

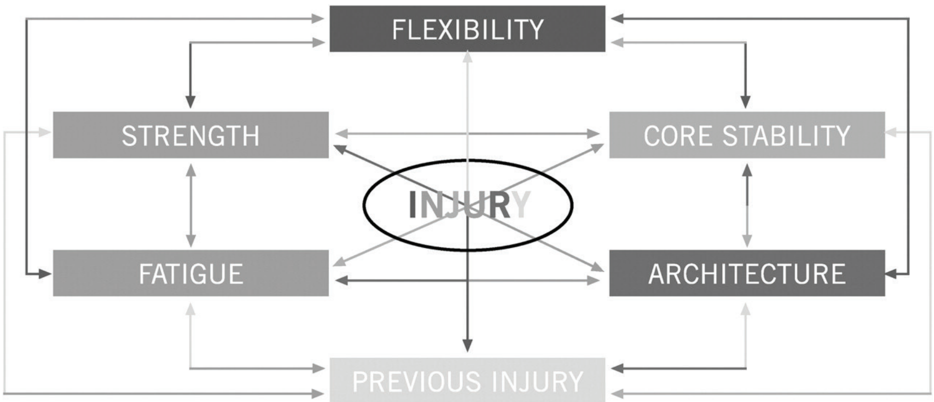

Figure 3. *Hamstring injury risk model adopted from Mendiguchia et al. (2012)* [17]

Injury prevention programs

Despite no evident modifiable risk factors for hamstring injuries in soccer players, improving eccentric hamstring strength seems to be an effective preventive intervention strategy[40–42]. Two effective injury prevention programs in soccer have been investigated extensively: The FIFA 11+ and the Nordic hamstring exercise.

The FIFA 11 and FIFA 11+ were developed to reduce overall soccer injury incidence and severity. The FIFA 11+ is the modified version of the FIFA 11. The FIFA 11+ took 20 minutes every training session and included an eccentric hamstring strength exercise – the Nordic Hamstring Exercise (NHE). The FIFA 11+ program was effective in reducing all soccer injuries including hamstring injury incidence[43,44].

The Nordic Hamstring Exercise program was specifically designed to prevent hamstring injuries. This program consists of one eccentric hamstring exercise, the NHE[40,45,46]. This program reduced hamstring injury incidence by 65% till 70% in both professional and amateur soccer players[40,45,46]. Thus, an increase in eccentric hamstring strength caused by the NHE[47], seems to be effective in hamstring injury prevention, which might implicate that an eccentric strength deficit is a risk factor for hamstring injury occurrence.

Although effective hamstring injury prevention programs have been designed and implemented, hamstring injury incidence has not decreased in the last 15 years[48]. A major challenge in injury prevention is compliance and long term adherence[49].

Implementation and adherence

More than two decades of hamstring injury prevention research has not resulted in a decrease in hamstring injury incidence and severity[48]. Instead an annual increase of hamstring injuries in soccer players has been seen in the last years[48]. The effectiveness of an injury prevention program depends on several aspects, in particular the effectiveness of the preventive measure, good compliance and the individual risk-taking behavior of the athlete[50]. Since effective injury prevention programs have been developed and knowledge is disseminated, reasons have to be found in lack of successful implementation or low adherence by the end-users.

In 1992 Van Mechelen et al. developed the injury prevention sequence. This worldwide applied injury prevention sequence consisted of four stages: (1) the extent of the problem, (2) the etiology and injury mechanisms, (3) introduction of preventive measures and (4) assessing the effectiveness of the intervention by registration of the new injury incidence and severity[51]. Thereafter, Finch et al. (2006) added two stages to the original injury prevention sequence and placed step 4 in an ideal (research) situation. The added stages focus on the effectiveness of the preventive measure in relation to success of the implementation, which together cover the effectiveness of injury prevention programs[50].

In **chapter 3** we describe the long term adherence for an effective hamstring injury prevention program and provide arguments to execute or not execute primary preventive measures.

Plyometric training and performance

Compliance is known to be a prerequisite for successful injury prevention programs [52,53]. To improve compliance, preventive programs should ideally consist of sport-specific exercises that are easily incorporated into the warming-up. If these exercises would also improve performance, it is assumed that motivation of players to execute these exercises and thereby compliance increases.

The most common activities in soccer are, sprinting, jumping, agility and shooting[54–57]. These activities require players to have excellent strength and endurance. Plyometric training is a type of strength training widely used in team sports to enhance sport-specific performance[58–64]. This type of training is also used in soccer players to improve sprint and jump performance, but is never used as a preventive measure for hamstring injuries. In **chapter 4** we describe the effectiveness of plyometric training in soccer-specific tasks.

Plyometric training and hamstring injury prevention

The effectiveness of plyometric training is based on the stretch-shortening cycle and encompasses abilities that are used to improve physical performance, but can also be applied in hamstring injury prevention[58]. Plyometric training is known for strengthening the elastic properties of connective tissue, improve the mechanical characteristics of the muscle–tendon complex and optimize cross-bridge mechanics and motor unit activation [60,62]. On top of the increase in (eccentric) strength, plyometric training can also improve core stability, intermuscular and intramuscular coordination and optimize biomechanics during sprinting and jumping[58].

To translate these characteristics to hamstring injury prevention, the focus lies in the stretch-shortening cycle. As stated before (see injury mechanism), the sprint-type hamstring injury occurs mostly in the late swing phase of the running and sprinting cycle and affects mostly the BFlh[11,19,20]. During this late swing phase the hamstring muscle undergoes a stretch-shortening cycle[58]. The hamstring has to eccentrically contract to decelerate the hip flexion and knee extension, isometrically contract to maintain position and concentrically contract to accelerate the hip extension and knee flexion for the next step[21–23]. In the late swing phase the BFlh reaches its peak stretch and the stretch increased by an increasing speed[21,23]. During that late swing phase larger amplitudes in activation of the glutes and core muscles can decrease the stretch on the BFlh[21,23,25,65]. Plyometric training with an accent on horizontal force production, would in theory increase glutes and core muscle activation, in combination with an increased eccentric contraction of the BFlh in the late swing phase.

In **chapter 5 and 6** we describe a new plyometric training program - the Bounding Exercise Program (BEP) - consisting of three exercises, designed to prevent hamstring injuries and achieve a high compliance during and after the study period. In **chapter 7** we evaluate the compliance of the program and explore differences in player characteristics and perceptions about the program between players that adhered better and players that adhered worse.

Return-to-play

Not all hamstring injuries can be prevented. Given high recurrence rates, secondary prevention should be considered as well to reduce overall hamstring injuries rates. The main concern from the medical staff is to treat the player optimal and make sure he returns to play as quick and safe as possible in order to minimize the disadvantage of absence of play for the team and to prevent new (hamstring) injuries for the player himself. This decision is ideally based on clear validated Return-to- Play (RTP) criteria. In **chapter 8** we give an overview of the RTP criteria after a hamstring injury and all relevant stakeholders in the RTP decision process.

Targeted prevention

To improve compliance of prevention programs, it is suggested to increase awareness of individual risk for injuries. It is assumed that players are then more willingly to participate in injury prevention programs[50]. To provide players with objective data about their individual risk of getting a hamstring injury, identification of prognostic factors for hamstring injury could be a solution. Based on the individual risk profile of players, including the sum of the risk-factors, technical and medical staff can advise specific players to participate in injury prevention programs. In **chapter 9**, we investigate the prognostic value of the Hamstring Outcome Score (HaOS).

Thesis outline

This thesis aims to reduce the incidence and severity of hamstring injuries and re-injuries by studying new risk factors, assess effectiveness of plyometric training on hamstring injury prevention and overcome compliance issues. Secondly, it aims to describe clear return to play definition and available criteria, and identify players at higher risk for hamstring (re-)injury.

At first, risk factors will be discussed. A lot of research focused on risk factors during soccer practice and match play[32–39], but no studies aimed to identify risk factors outside the soccer field. Therefore, we investigated the off-field activities of amateur soccer players as potential risk factors that might contribute to hamstring injury occurrence (**chapter 2**).

Following the TRIPP framework, adherence in the real- world context needs to be evaluated to understand its true effect[66]. In **chapter 3**, we described the long term adherence and reasons for (not) performing the effective Nordic Hamstring Exercise program.

Adherence for the Nordic Hamstring exercise program is known to be low in both professional and amateur soccer players[49]. We hypothesized that when an injury prevention program also increases sport-specific performance trainers and soccer players are more willingly to adhere to the program. To provide the basis for a new injury prevention program that also increases performance, we conducted a systematic review and meta-analysis on effects of plyometric training on soccer-specific performance outcomes in adult male soccer players **(chapter 4).**

Based on the effectiveness of the increase of eccentric hamstring strength caused by the Nordic hamstring exercise and effectiveness of plyometric training on soccer-specific performance, we developed the bounding exercise program (BEP) as a hamstring injury prevention program. The Bounding exercise is used frequently in track and field to improve sprint performance. The program we designed is based on both eccentric and plyometric exercises and is supposed to be continued during an entire competition.

The design of the cluster-randomized trial evaluating the effectiveness of the BEP is described in **chapter 5.**

We hypothesized that the BEP would prevent 50% of the hamstring injuries in male amateur soccer players and that compliance and long term adherence would maintain high. In **chapter 6** the results of the cluster-randomized controlled trial are described.

The main reason to develop a new hamstring injury prevention program, that reduces hamstring injury incidence and increases soccer-specific performance, was to increase long term adherence. In **chapter 7** we evaluated the BEP and presented the adherence during the cluster-randomized controlled trial. In this evaluation, differences in player characteristics and perceptions about the BEP between players that adhered better and players that adhered worse were explored.

Unfortunately not all hamstring injuries can be prevented at this point, this results in the importance of clear and validated RTP criteria. Therefore, we conducted a qualitative systematic review about the definition of RTP and criteria for a safe RTP after a hamstring injury **(chapter 8).**

Adherence is a major issue in injury prevention in general and since literature shows that players are more willingly to participate when they have insight in their individual risk. Previous injury is the only evident risk factor for hamstring injury and the HaOS subjectively evaluates a lot of factors proposed as potential (re-)injury risk factors[67,68]. Therefore, we decided to investigate the prognostic value of the hamstring outcome score (HaOS) in combination with previous hamstring injury. With this prognostic factor study, the aim was to provide players and staff with more guidance in targeting the players at higher risk and prescribing targeted prevention programs **(chapter 9)**.

In **chapter 10** we reflect on the main findings of this thesis, provide future perspectives and describe practical implications.

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2

Are off-field activities a risky business for hamstring injuries in male amateur football? A prospective cohort study

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ABSTRACT

Amateur football players generally deal with an occupation or study or study on top of their football career. These off-field activities could play an important role in hamstring injury occurrence through high load and poor recovery. Therefore, the aim of this study was to explore the causal relation between off-field activities and the development of hamstring injuries in male amateur football players. A total of 399 players filled in a questionnaire concerning off-field activities (i.e. work and study type and hours, travelling time, sleep, and energy costs) and history of injury as a part of a cluster-randomized controlled trial. Throughout one season, both players and medical staff reported injuries weekly. Multivariable Firth corrected logistic regression models were used to explore associations between off-field activities and hamstring injuries. During the season, a total of 65 hamstring injuries were recorded. No evidence was found for causal relations between off-field activities measured at baseline and hamstring injuries. Previous injury was associated with hamstring injuries (OR ranging from 1.94[1.45–2.61] to 2.01[1.49-2.73]). Future studies should combine the use of sensor technology with subjective measurements to measure on- and off-field activities. When measured frequently enough, a dynamic system approach could detect subtle changes over time.

Keywords: Risk factors, Activities of Daily Living, Psychosocial Factors, Soccer, Athletic Injuries

BACKGROUND

Hamstring injuries are the number one muscle injury in adult male football and cover 15.9% of all injuries in male amateur football.[1,2] In combination with the knowledge that one third of the hamstring injuries will recur following return to sport and a relative high injury burden these injuries are of major concern to both players and coaches.[2,3] Hamstring injuries are known to affect physical functioning and can result in a decrease of individual performance and team performance as well.[4–6] As a result of time loss in sport, school and work following hamstring injuries, social and medical costs can eventually increase.

Because most amateur football players combine playing football with activities off the football field, such as work or school, they are exposed to various factors that could contribute to hamstring injury. These factors and their association with hamstring injury are not examined thoroughly in amateur football. It is known that the identification of causal factors associated with injuries is a prerequisite for the development of effective prevention strategies and in general, all factors should be considered in the dynamic model of injury etiology.[7,8] Therefore, it is important to identify factors that are associated with injury in amateur football players from a complementary perspective.

Over the years different theoretical models have been developed in which the injury mechanism is mainly viewed from a biophysiological perspective related to the sport, focusing on factors such as strength and neuromuscular control,[8] and a biomechanical perspective, focusing on factors such as equipment and training surface.[9] Off-field activities such as work and study could be included in the biopsychological pathway but are often neglected as potential causal factors that contribute to hamstring injuries in amateur football players.

A proposed conceptual framework assumes that load and recovery of training should be in balance for optimal performance and prevention of injuries.[10,11] The balance includes both physical and psychological load of match play and training on the one side and the recovery enhancing factors (i.e. sleep in between matches and training sessions) on the other. In addition to the balance of load and recovery on the field, the amateur football players are exposed to physical and psychosocial load during off-field activities such as work and study.[10,12] Therefore, we assume that both on-field and off-field activities can contribute to the amount of load and recovery and therefore increase the injury risk.[10]

Amateur football players spend most of their time off the field on an occupation or study which can lead to an increase in physical and psychological load on players. These off-field activities during occupation or study can increase physical through an increase in specific movements such as lifting or kneeling which are known to be associated with acute or overuse injuries.[13–15] Therefore these off-field activities are important to consider in the development of hamstring injuries in amateur football players. Furthermore, these off-field activities could lead to more daily hassles (i.e. the stress from many minor daily problems, irritations, or changes) which are known to have impact on the association with football injuries.[16] Increased physical and psychosocial load caused by off-field activities in combination with poor recovery (i.e. through decreased sleep duration or quality), may lead to hamstring injuries.[17,18] Therefore, it is important for coaches and staff to have insight in the physical and psychological load their players endure besides their football activities and their relation to hamstring injuries. In that way, they can adapt their training strategies based on individual needs.

To date, age of the player and previous hamstring injury are the most important factors that have been linked to the occurrence of hamstring injuries in male amateur football players.[19,20] Evidence regarding off-field activities and the association with hamstring injuries is lacking, but could contribute to the development of adequate prevention strategies.[21] The aim of this study is to explore whether there is an association between off-field activities on the one side and the development of hamstring injuries in male amateur football players on the other. We hypothesize that an increased total load through a higher burden during off-field activities in combination with a decreased recovery is associated with developing a new hamstring injury.

METHODS

Study design and participants

This is an exploratory analysis from the Hamstring Injury Prevention Study – Bounding Exercise Program trial (HIPS-BEP), a longitudinal prospective cohort study of which the aim was to determine the preventive effect of the Bounding Exercise Program (BEP) on hamstring injury incidence and severity.[22,23] This analysis aims to explore the association between off-field activities and both primary and secondary hamstring injuries. In the HIPS-BEP study, 32 Dutch first class amateur football teams were included and monitored through the 2016/2017 football season as a part of a recently completed cluster randomized controlled trial (cRCT) on the preventive effect of the bounding exercise program (BEP) on hamstring injuries.[23] In the cRCT, teams were randomized into an intervention group that received a gradual increasing bounding exercise program or a control group. There was no evidence found for differences in hamstring injury incidence and severity between the intervention and the control group.[23] In this study, the entire cohort was used to explore the association between the daily activities recorded at baseline and hamstring injury. All players provided written informed consent prior to the start of the study. The trial was approved by the Medical Ethics committee of University Medical Centre of Utrecht (16–332\C) and is registered in the Dutch trial register (http://www.trialregister.nl/trialreg/index.asp) (NTR6129). The report of this study follows the STROBE guidelines.[24]

Eligibility criteria

Male amateur football players were eligible when between 18-45 years old and registered as a player in the first team of a football club active in the Dutch first-class amateur competition. Players were excluded when they: (1) gave no informed consent, (2) did not complete all questions related to off-field activities in the baseline questionnaire, (3) joined the included teams after the start of the study or (4) had insufficient Dutch language skills to fill in the questionnaires.

Baseline measurements

Prior to the 2016/2017 football season, all enrolled participants completed a questionnaire on player characteristics and off-field activities (Table 1) which was provided in Dutch. The player characteristics included age, body height, body weight, number of years' experience as football player, standard field position, and leg dominance. Previous hamstring injury was quantified as the total number of hamstring injuries in the previous season. Work and study activity were quantified by the weekly hours spend on work and study in regular work or study weeks. One researcher (JB) categorized the intensity of work and study in low, intermediate or high physical activity according to previously proposed categories.[25] For example, construction work was labeled as high intensity occupation, physiotherapist as an intermediate intensity occupation and teacher as a low intensity occupation in general. In the case of uncertainty, two researchers (PAvdH, MB) were consulted to provide consensus. Travelling time and sleep were measured in hours. Finally, as an indicator of the load-recovery balance throughout the season, the included players scored energy costs of all activities besides football on a scale ranging from 0 (no energy at all) to 10 (all of my energy) similar like strength or psychological predictors are measured in pre-season.[26,27]

Outcome measurements

Every week all players received four short questions regarding the number of training minutes, number of match minutes, hamstring injury occurrence and general injury occurrence. Injuries were divided into hamstring injuries, other injuries, and recurrent (hamstring) injuries. A hamstring injury was defined as any physical complaint affecting the posterior side of the upper leg resulting in an inability to play or train regardless of the need for medical attention.[28] In the case of a hamstring injury, both the player and the medical staff were contacted by phone or email to verify the hamstring injury and received a standardized hamstring injury questionnaire to record incidence, severity, and etiology of the injury that was filled in separately. We instructed the medical staff of all teams how to register hamstring injuries before the start of the study to ensure consistency regarding hamstring injury classification.[23]

Players who sustained at least one hamstring injury that was classified as mild (4 – 7 days), moderate (8 – 28 days), or severe (> 28 days) were coded injured (1). All other players were coded uninjured (0) for the analysis, following the consensus statement on injury

Table 1. *Description of variables in the baseline questionnaire*

Variable	Unit/description
Group allocation	
Intervention or control group	BEP* or CON**
Previous injuries	
Hamstring injury history at the beginning of the study	Number and side of injury
Load	
Work duration	Hours per week
Work intensity	Low, intermediate, or high physical activity
Study duration	Hours per week
Study intensity	Low, intermediate, or high physical activity
Travelling time	Hours per week
Recovery	
Sleep	Hours per night
Load-recovery balance	
Energy cost of all activities	Scale, 0 (no energy at all) to 10 (all my energy)

*Note. * = bounding exercise program. ** = control group*

definition.[28] Recurrent injuries are defined as an injury of the same type and at the same site as the index injury occurring after a player fulfilled the criteria of return to play.[29] In the case of a recurrent hamstring injury, the player and medical staff received the same hamstring injury questionnaire as for the primary hamstring injury.

Data analysis

Statistical analysis was performed in R Statistical Software version 3.4.1 (Foundation for Statistical Computing, Vienna, Austria)[30] with the brglm package (version 0.6.1) and logistf (version 1.22) package.[31,32] Because the analysis of variables that could explain the hamstring injuries that occurred during the HIPS-BEP study is a secondary analysis, the players were not randomized for the purpose of this study. To control for group allocation, group allocation was included in the analysis. Therefore, we selected confounders using clinical reasoning and analyzed the data accordingly. The variables that were considered for inclusion in the analysis were: work and study duration, work and study intensity, travelling time, sleep and energy costs. Prior to multivariable analysis, the data was screened and checked for data-entry errors, outliers and missing data. Missing data was assumed Missing At Random (MAR) as defined by Rubin[33] and were imputed by multiple imputation with chained equations,[34] using the variables: age, body weight, body length, work/study duration, work /study intensity, traveling time and sleep.

Since the outcome of an hamstring injury was relatively rare, we analyzed the data using multivariable logistic regression analysis with Firth correction to penalize log likelihood and adjust for small sample bias.[35] To assess a possible causal association between the off-field activities and hamstring injury, different multivariable models were tested. In the first analysis, all the off-field activities were included. In the final analysis, four models were tested for the four different exposures; three models on load (work, study and travelling time) and one on recovery (sleep). In all models, the variables group allocation and previous injury were included. In the work model the interaction term work duration*work intensity was included. In the study model the interaction term study duration*study intensity was included. Incidence of previous injuries was analyzed as a continuous variable to minimize loss of information.

RESULTS

Participants and descriptives

A total of 588 adult male amateur players from 32 football teams were assessed for eligibilty.[23] 400 players filled in the baseline questionnaire of which 1 player completed no questions related to off-field activities. The remaining 399 players were included in the final analysis. Reasons for exclusion were: long-lasting injuries, no weekly registration and no completion of baseline questionnaire. An overview of baseline data is presented in Table 2.

There were 39 cases with missing variables on the off-field activities. Percentage of missing data ranged from 0.5% to 3.7% on the variables category of work (0.07%), work hours (0.5%), study category (0.5%), study hours (2.5%), travelling time (1.8%), sleep (1.5%). There was no missing data on the previous and current hamstring injury data.

Table 2. *Characteristics of male amateur football players (n = 399)*

Characteristics	Mean (SD)
Age (years)	24.81 (4.35)
Weight (kg)	78.77 (7.89)
Height (cm)	183.99 (6.36)
Experience (years)	18.68 (4.62)
Training exposure (min per week)	143.78 (80.08)
Match exposure (min per week)	56.53 (45.64)

Outcome data

Table 2 describes the player characteristics and exposure and Table 3 describes participants' off-field activities at baseline and injury history. Players spent on average 38.1 hours per week on work and study. Furthermore, they spent on average 7.42 hours per week travelling and slept an average of 7.36 hours per night. At the start of the study, all activities had an energy costs of 6.98 on a scale of 1 to 10. Players sustained on average 0.34 hamstring injuries (in total 93 injuries) in the previous season.

Table 3. *Descriptive data of off-field activities and injury history concerning male amateur football players (n=399)*

Variables	Mean (SD)
Work duration (hours per week)	27.13 (17.72)
Study duration (hours per week)	10.53 (14.68)
Total duration of work and study (hours per week)	38.10 (10.62)
Travelling time (hours per week)	7.42 (6.78)
Sleep per night (hours per week)	7.36 (1.17)
Energy costs (on a scale of 0 to 10)	6.98 (1.80)
Hamstring injuries in previous season	0.34 (0.68)

In the 2016/2017 season, 65 hamstring injuries were reported and validated by a follow-up questionnaire. Eight of these 65 hamstring injuries were recurrent injuries (12.3%). Of the 65 injury questionnaires, 5 were not filled in completely. Of the 65 injuries, 29 injuries occurred on the right leg, 27 on the left, and 6 on both legs. There were 36 acute and 23 overuse injuries, and one injury had an unknown origin. Injuries occurred mostly around matches (before match: 2 injuries, during match: 29 injuries, after match: 11 injuries) and in lesser degree during training (15 injuries during training). Of the validated injuries, 53 players had at least one injury with a severity of mild or higher and these players were included in the analysis for off-field activities. The mean duration of the hamstring injuries was 23.57 (ranging from 4 to 104 days).

Main results

The first multivariable logistic regression model was fitted on the non-imputed data and included work hours and category of intensity, study hours and category of intensity, travelling time, sleep, energy costs and previous hamstring injury. In this model the only variable showing a significant ($p < 0.05$) association with a hamstring injury was previous hamstring injury (adjusted odds ratio [OR] 1.92 [95% CI: 1.42–2.62]). All the off-field activities were not significant associated with hamstring injury.

In the second analysis, a multivariable logistic regression analysis with all variables included was repeated on the imputed data. In this model the only variable that is associated significantly with a hamstring injury was previous hamstring injury (OR: 1.97 [95% CI: 1.45-2.67]). All the other off-field activities were not significantly associated with hamstring injury.

In the final analysis, four models were fitted on the imputed data. Respectively: work, study, travelling time and sleep. The results of the final regression analysis are shown in tables 4-7. In all models, only previous hamstring injury was significantly associated to a new hamstring injury. All other off-field activities were not significantly associated with a new hamstring injury.

Table 4. *Multivariable logistic regression analysis for work regarding male amateur football players (n = 399)*

Variables	**OR**	**95% CI***
Intercept	0.09	0.02–0.35
Group Allocation (BEP/CON**)	0.92	0.50–1.69
Previous Injury (average)	1.94	1.45–2.61***
Work duration (hours per week)	1.00	0.90–1.10
Work Intensity		
Low	2.08	0.35–12.25
Intermediate	0.40	0.06–2.78
High	0.31	0.02–3.78
Work duration×Work Intensity Low	1.06	0.89–1.26
Work duration×Work Intensity Intermediate	0.98	0.88–1.10
Work duration×Work Intensity High	1.02	0.91–1.15
Energy Costs (scale 1 – 10)	1.03	0.92–1.16

Note. * = *Confidence interval;* ** = *bounding exercise program/control group,* ***= *p < 0.001*

Table 5. *Multivariable logistic regression analysis for study regarding male amateur football players (n = 399)*

Variables	**OR**	**95% CI***
Intercept	0.07	0.02-0.29
Group Allocation (BEP/CON**)	0.89	0.48-1.66
Previous Injury (average)	2.01	1.49-2.73***
Study Duration (hours per week)	1.01	0.94-1.08
Study Intensity		
Low	0.66	0.20-2.22
Intermediate	15.40	0.85-278.77
Study Duration×Study Intensity Low	1.06	0.89-1.28
Study Duration×Study Intensity Intermediate	1.01	0.93-1.10
Energy Costs (scale 1 – 10)	0.81	0.62-1.05

Note. *= *Confidence interval;* ** = *bounding exercise program/control group,* ***= *p < 0.001*

Table 6. *Multivariable logistic regression analysis for travelling time regarding male amateur football players (n = 399)*

Variables	**OR**	**95% CI***
Intercept	0.08	0.02-0.31
Group Allocation (BEP/CON**)	0.91	0.50-1.67
Previous Injury (average)	1.97	1.47-2.65***
Travelling Time (hours per week)	0.99	0.94-1.04
Energy Costs (scale 1 – 10)	1.06	0.89-1.27

Note. * = *Confidence interval;* ** = *bounding exercise program/control group,* ***= *p < 0.001*

Table 7. *Multivariable logistic regression analysis for sleep regarding male amateur football Players (n = 399)*

Variables	OR	95% CI*
Intercept	0.08	0.01-0.70
Group Allocation (BEP/CON**)	0.93	0.50-1.70
Previous Injury (average)	1.99	1.48-2.67***
Sleep (hours per week)	1.00	0.78-1.27
Energy Costs (scale 1 – 10)	1.06	0.88-1.26

Note. * = *Confidence interval;* ** = *bounding exercise program/control group,* ***= *p < 0.001*

DISCUSSION

The aim of this present study was to identify off-field activities related to developing hamstring injuries in male amateur football players. Although players spent a large amount of time on off-field activities, no evidence was found for a significant association between the off-field activities at baseline with developing hamstring injury throughout the season. A previous hamstring injury was significantly associated to hamstring injury in the multivariable analyses (OR ranging from 1.94[1.45–2.61] to 2.01[1.49-2.73]) which is consistent with results reported earlier.[36,37]

In this study, the reinjury rate was 12.3% with a high rate of acute and strain injuries compared to overuse and other types of injuries. In addition, injury rate was higher during matches compared to training. These injury characteristics are in line with other studies.[36–41]

We hypothesized that amateur players often combine football with off-field activities such as work and study. This was confirmed by the total time spent on these activities which was about 38 hours per week besides their football activities at baseline. We expected that the intensity of work would be important during specifically high demanding occupations in which players frequently lift or kneel down. In previous studies, it was found that these physical demands, such as lifting or kneeling down during occupations, were associated with acute and overuse injuries, such as meniscal tears, sprains or strains and osteoarthritis.[13,14,42,43] This could possible apply to the hamstrings as well. One could also argue that these activities improve an individual's physical fitness and motor or functional abilities and result in a protective adaptation.[44] However, evidence to support this claim is lacking. In our study, we did not quantify the load of each individual player performed during work or study. Alternatively, we categorized type of work and study intensity following recent recommendations.[25] However, these categories were based on accelerometer data and gave a global estimate of intensity but do not capture the mechanical local load placed on the lower extremity and therefore may lack specificity. This lack of specificity might also be true for the psychosocial aspects of work and study. We captured hours spent on these activities but could not objectively register the number of daily hassles for each individual.

Finally, the included players spent on average more than 7 hours per week travelling. In this study travelling time was determined in hours per week, but mode of transportation was not specified. It is important to realize that in the Netherlands cycling is a popular form of transportation. Cycling contributes to a better physical fitness level and could even result in more hamstring muscle strength which could possibly protect the hamstrings.[45,46] Although speculative, the lack of association between travelling time with hamstring injury could be determined by the distribution of players who use an active form of transportation (i.e. cycling or walking) and players who use a passive form of transportation (i.e. train or car).

To compensate for a higher exposure in off-field activities, sleep is known to be important for recovery. However, the sleep duration of amateur players in our study was relatively low. It is known that professional players sleep on average 8 hours and 11 minutes,[47] while the amateur players in our study slept 7 hours and 22 minutes. We hypothesized that a decreased sleep duration results in a decreased recovery and would affect the injury rate which is also seen in other athletes.[48,49] No evidence for an association between sleep duration and hamstring injury was found. We measured sleep duration through self-report. While self-reported sleep duration has a strong resemblance to objective sleep duration measurements as polysomnography, these subjective measures about duration do not include sleep quality.[50] Sleep quality is also known to influence the load-recovery balance and may be more important to determine when identifying factors associated to injury.[51,52]

The high amount of time spent on off-field activities and the decreased duration of sleep suggests a disturbed load-recovery balance. As this balance is largely determined by an individual's capacity, a possible explanation for a lack of association could be that we did not take individual differences into account. As each individual has a different capacity, similar load and recovery can have different consequences.[10] Some players may adapt to higher loads while for other players this leads to overload and increased injury risk.[10,53,54] Given time constraints, we could not determine physical and psychosocial capacity of each individual and thus only captured the external load where players were exposed to. Consequently, the actual impact of these loads on individual players was not registered. As an alternative, we captured the total load-recovery balance, with the total energy costs of all activities. While the average score on this question was relatively high (6.98) when compared for example to daily perceived exertion in office workers and cleaners,[55] the total energy cost score was not significantly associated with hamstring injuries.

One of the limitations of this study and with screening at baseline in general, is that all potential factors associated with hamstring injury were only assessed once. While this is often done with capacities such as strength or psychological predictors in the preseason,[26,27] this form of screening does not include variation during the season. For example, it is known that daily hassles do change from week to week in elite junior, high school, and senior football players and these changes were associated with a higher injury incidence.[56,57] Thus, a longitudinal design with repeated measures would be more appropriate to account for these fluctuations over time. For future research, it would be interesting to measure off-field activities repeatedly and combine them with, for example daily hassles, so that a dynamic system approach can be used which could contribute to insight in a player's resilience.[58,59] Additionally, the number of injuries remained relatively low in the present study which resulted in sparse data. To avoid sparse data bias, we used the Firth correction on the multivariable logistic regression analysis. The Firth correction removes a portion of small sample bias by penalizing the likelihood and in combination with profile likelihood based confidence intervals the accuracy of logit coefficients in small samples is improved.[35] On the other hand, this study is one of the largest prospective cohort studies concerning hamstring injuries in amateur football players, including 399 amateur players from clubs across the whole country and 65 hamstring injuries verified by both the player and medical/technical staff. This makes it possible to translate the results to other male amateur first-class teams in similar competitions. Another major strength of this study is that this is the first study to our knowledge that examines the physical load of off-field activities and the association with hamstring injuries in male amateur football players. Although all the precautions that were taken (multiple imputation, Firth correction and use of different models), the analysis remains exploratory and therefore the results need further evaluations with larger samples.

CONCLUSION

In this prospective study, no evidence was found for the association between other off-field activities and the development of hamstring injuries. This study confirmed once more that a previous hamstring injury is strongly associated with the development of a new hamstring injury in male amateur football players.

PRACTICAL IMPLICATIONS

In future prospective studies, the physical and psychosocial aspects of off-field activities could be measured more frequently to detect subtle changes over time. Furthermore, the individual capacities could be determined to include individual tolerance of load factors. A possible solution to measure the contribution of total off-field activities is to monitor players using sensor technology in daily life. Further research could, for example, combine actigraphy with self-reported measures for work and/or study, travelling time, sleep intensity and duration.[60] These measurements should be combined with the quantification of on-field activities. When measured frequently enough, interactions between all these activities could be determined using a dynamic system approach and relations that support the occurrence of hamstring injuries can be found.[61] All these aspects could lead to a better understanding of hamstring injury occurrence, which in result could eventually lead to (the implementation of) adequate prevention strategies.

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Effective but not adhered to: How can we improve adherence to evidence-based hamstring injury prevention in amateur football?

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ABSTRACT

Objectives: To investigate adherence to a Nordic hamstring exercise (NHE) program in a real-world context of male amateur football, and the perceptions of end users (players) and intervention deliverers (coaches and medical staff) about adherence to this proven effective program.

Design: Retrospective cohort study.

Setting: Dutch amateur football.

Participants: Two hundred sixty-four players, 23 coaches, and 29 medical staff from Dutch amateur football teams that participated in a national randomized controlled trial 2 years earlier.

Independent Variables: Nordic hamstring exercise program.

Main Outcome Measures: Nordic hamstring exercise program adherence during 2014 and 2015. Intervention or control group allocation during the trial, transfers, and personal perception about adherence to the program were also examined.

Results: Of all players, 69% reported never, 16% sometimes, 6% frequently, 5% often, and 4% always performing exercises of the NHE program. Adherence to the NHE program was higher among players who had been in the NHE arm of the previous trial and among players who had not been transferred to another club compared with players who had been transferred. Key factors in stimulating players to adhere to the NHE program were knowledge of the NHE and personal motivation. Coaches and medical staff members also mentioned personal motivation and consensus with team staff as key factors to encourage NHE adherence.

Conclusions: Among high-level male amateur football players, adherence to an evidence-based hamstring injury prevention program was very low. It is essential to recognize factors that stimulate or limit adherence to injury prevention programs for effective programs to actually lead to a reduction in hamstring injuries in a real-world context.

Key Words: hamstring injury, prevention, football, soccer, adherence

INTRODUCTION

Hamstring injuries are a primary target for injury prevention in football because they are the most common muscle injury and have a high recurrence rate (12%-33%).[1,2] On average, a team squad (usually 25 players) suffers about 5 to 6 hamstring injuries each season, losing a total of 80 days from football (including match and training) activities. These injuries not only have severe personal, medical, and financial consequences, but are also related to decreased performance caused by the unavailability of players for matches.[3] Since 2001, the rate of hamstring injury in football has increased by 4% annually.[1]

The Nordic hamstring exercise (NHE) program was specifically developed to prevent hamstring injuries (Figure 1, NHE). The NHE can easily be incorporated into regular training sessions and increases eccentric hamstring strength.[4–6] Large-scale randomized controlled trials (RCTs) have shown that when the NHE program is incorporated in regular training, the rate of first-time hamstring injuries is reduced by more than 60%,[4,6] and recurrent injury rates are reduced by 85%.[4]

Unfortunately, injury prevention programs that have proven to be effective in trials do not necessarily reduce injury incidence in a real-world setting.[7] There is still a gap between compliance in a research setting (eg, an individual following professional recommendations regarding prescribed dosage, timing, and frequency of an intervention) and adherence in a real-world setting (where the process is influenced by environment, social context, personal knowledge, motivation, skills, and resources).[8,9] Sports injury prevention programs can only benefit the health of athletes if they are adopted by the intended end users (eg, the athletes themselves).[10,11]

To better understand health-promoting behavior, social psychologists developed the health-belief model (HBM)[12,13] in the 1950s, which is still widely used in health behavior research. This model suggests that people's beliefs about health problems, perceived benefits of action and barriers to action, and self-efficacy explain (lack of) engagement in health-promoting behavior.[12–14] In this model, the perceived susceptibility (ie, beliefs about the risk of sustaining an injury) and the perceived seriousness (ie, beliefs about the consequences of the injury for health and sport activities) lead to the perceived threat. The perceived threat, along with the perceived benefits (ie, beliefs about the effectiveness of injury prevention) and perceived barriers (ie, beliefs about the negative aspects of adopting injury preventive measures), self-efficacy (ie, the player's belief how well he can execute preventive exercises) and cues to action (ie, stimuli to motivate players to take action to prevent injuries) ultimately lead to the likelihood of engaging in health-promoting behavior. Consequently, some studies have shown that adoption of preventive measures can be stimulated, and inhibited, by players' motivation,[15] staff support,[16,17] and knowledge about injuries and injury prevention.[18–20]

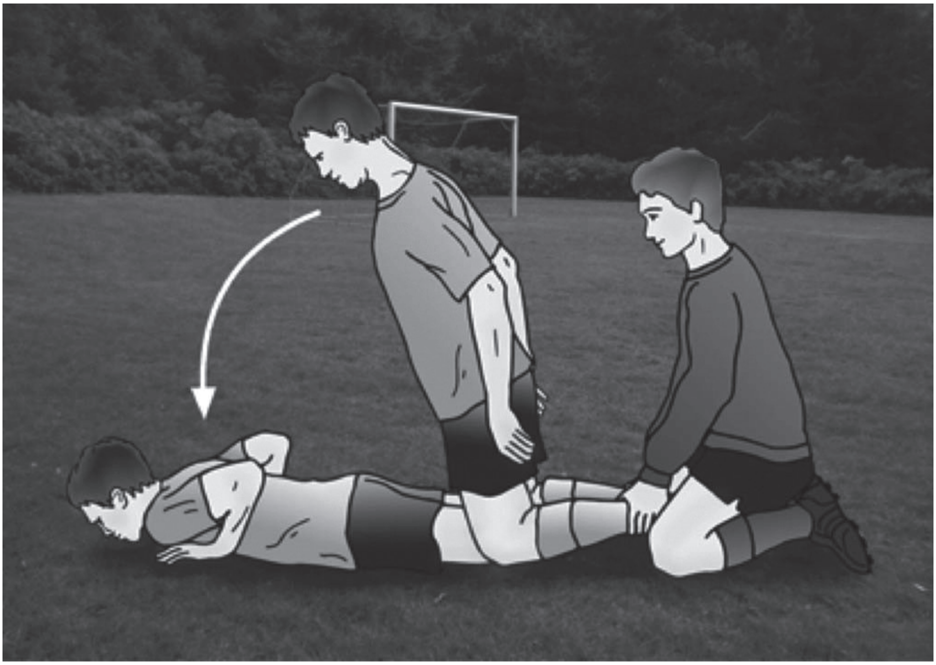

Figure 1. *The Nordic hamstring exercise.*

Recently, a study showed that the NHE program, for which there is compelling evidence of effectiveness, has not been adopted by the majority of football players in Champions League teams and Norwegian Premier League football teams (where the pioneer research was conducted).[21] However, the arguments for nonadherence to NHEs were not investigated, and factors that could improve NHE adherence were not addressed either. Furthermore, amateur footballers are the largest subgroup of football players, and there are significant differences between professional and amateur football in terms of medical staff, level of play, financial considerations, and perceptions about injury prevention, which could all influence adherence to injury prevention programs.

Therefore, the aim of this study was 2-fold: (1) to determine adherence to the NHE program in a real-life context of male amateur football players, and (2) to investigate the perceptions of targeted end users (eg, players) and program deliverers (eg, coaches and medical staff) regarding adherence to the evidence-based NHE program for the prevention of hamstring injuries.

MATERIALS AND METHODS

This study was conducted as a follow-up of a large cluster RCT, with data collection during 2013, of the preventive effect of the NHE program on hamstring injuries in male amateur football players.[6] The RCT was designed and performed in close collaboration with the Royal Netherlands Football Association (KNVB).[22] Following excellent compliance (91% of players performed all sessions) and high effectiveness [odds ratio 0.282; 95% confidence interval (CI), 0.110-0.721, P=0.005] in the RCT, a dissemination strategy was conducted to share results with the Dutch (amateur and professional) football medicine community. Study findings were presented in the media, in courses, at conferences, and in (scientific) journals and by organizing a meeting for all participating coaches and medical staff (both intervention and control groups) to share and discuss the results of the study as well as the future implementation of the NHE program. The Medical Ethics Committee of the University Medical Center Utrecht approved the follow-up study (No. 15/661), and ethical guidelines were followed. The follow-up data in this study entail adherence data of 2014 and 2015, which is the 2-year period immediately after the RCT was conducted and when there was no monitoring by the research team anymore. Before the study, participants were informed of the study aims and procedures. Informed consent was obtained from all players, coaches, and medical staff [eg, (sports) physiotherapists and/or sports masseurs].

All first-class amateur football players (n=579), coaches (n=38), and medical staff (n=47) involved in the RCT were invited to participate in the follow-up study through email and/or phone if there was no response to the email. Each potential participant was contacted with a minimum of 3 attempts through phone and/or email. Participants were excluded if they did not provide informed consent or if they had not been active at top amateur playing level (eg, professional or more than one level below the level of the original RCT) for 1 year or longer during follow-up.

A questionnaire addressing adherence to the NHE program was developed specifically for players, coaches, and medical staff. The first part of the questionnaire focused on measuring NHE adherence by the intended end users (eg, players). The second part of the questionnaire focused on potential factors that could contribute to adherence, based on elements of the HBM.[12–14] These factors, such as knowledge, (personal) motivation, effectiveness, and environment, were extracted from the scientific literature on compliance and/or adherence to exercise programs in sports.[15–20] To provide insights on injury perceptions, self-efficacy, and cues to action and ultimately their likelihood of adhering to the NHE program, players, coaches, and medical staff were asked to indicate which factors contributed to their adherence to the NHE program.

During an independent peer-review procedure, the questionnaire was pilot tested by 4 experts in the field of sports injury research to ensure clarity of the questionnaire,

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suitability to the participants, reader friendliness, and time consumption. Subsequently, a standardized interview was developed, which was pilot tested before data collection to ensure uniformity and standardization of the data collection procedure. Two independent researchers (P.O. and M.K.) administered the questionnaires through structured telephone interviews from November 2015 to January 2016. Answers were entered on a standardized registration form.

The data were analyzed using SPSS version 23.0 (IBM Corp, New York, NY). Statistical significance was set at 0.05 for all tests. Descriptive statistics (mean values and SDs) were used to describe baseline characteristics and adherence data. The full NHE program consisted of 25 sessions in 13 weeks.[6] Performance of the program was classified on a Likert scale in 5 categories as never (0 sessions), sometimes (1-8 sessions), regular (9-16 sessions), often (17-24 session), and always (25 sessions or more). In addition, t tests were performed to analyze potential group differences regarding adherence between (1) intervention versus control players, (2) players with and without a history of hamstring injury, and (3) players who had been transferred to another club or remained at the club during the follow-up. Factors that could influence adherence were scored on a 3-point Likert scale (less important, neutral, and important). An item was considered important if 75% or more of the respondents considered it important.[23]

RESULTS

A total of 664 participants from the original RCT were invited to participate in this follow-up study. After exclusion and loss to follow-up, 264 players, 23 coaches, and 29 medical staff were included (Figure 2, flowchart). Of the 264 included players, 135 (51.1%) had been in the intervention group in the original RCT and 129 (49%) had been in the control group. Baseline characteristics of all players, coaches, and medical staff members are summarized in Table 1.

After approximately 2 years, 69% (n=180) of the participants reported never performing the NHE program and 14% (n=38) reported sometimes performing the exercises (1-8 sessions). The NHE program was performed on a regular basis (9-16 sessions) by 10% (n=27), often (17-24 session) by 4% (n=10), and always by 3% (n=8) of the participants (Figure 3).

Adherence to the NHE program was significantly higher in those players who were in the intervention group in the previous trial than in those who were in the control group ($t= -4.460$; 95% CI: -0.851 to -0.329; $P <0.001$) and in players who remained at their club compared with players who transferred to other clubs ($t=2.572$; 95% CI: 0.081-0.612; $P=0.011$). There was no statistically significant difference in adherence ($t=0.608$; 95% CI:

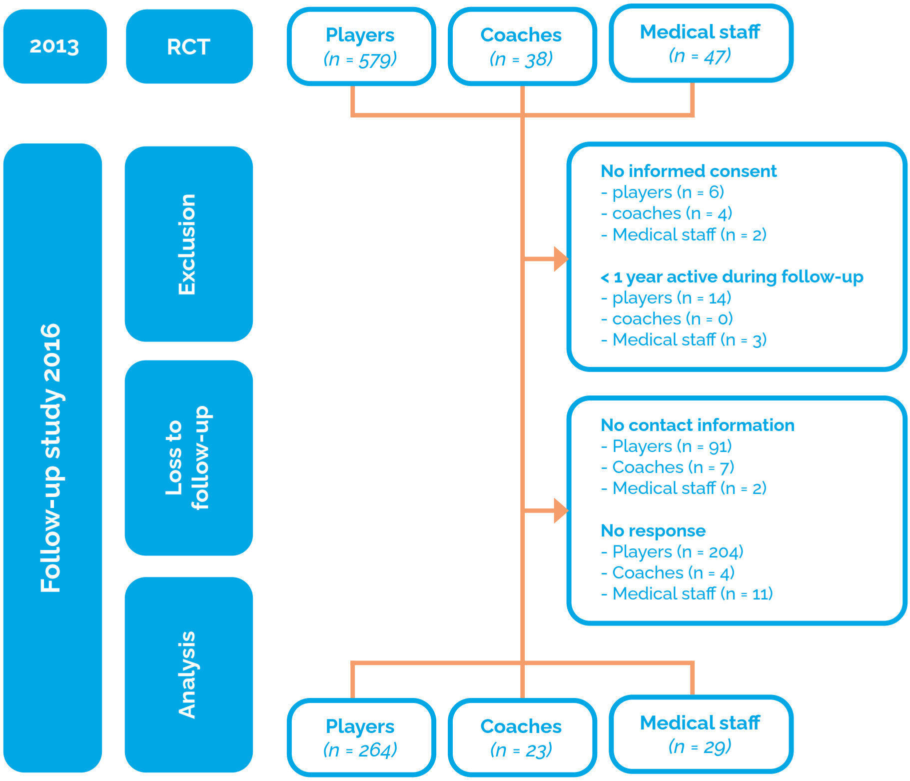

Figure 2. *Flowchart of the study population.*

0.231-0.437; P=0.544) between players with and without a history of hamstring injury during the follow-up period.

Participants' perceptions of factors that contributed to maintenance or increased adherence to the NHE program for the prevention of hamstring injuries are provided in Table 2. Some factors considered by players, coaches, and medical staff members to contribute to continued or increased adherence to the NHE program overlapped (Table 2), although there were some role-specific differences.

Players stated that knowledge of the NHE program and personal motivation were the primary reasons to perform the exercise program (Table 2). Coaches stated that effectiveness and knowledge of the NHE program, and personal motivation were the primary reasons to use the program. Medical staff stated that effectiveness and knowledge of the NHE program, consensus with the team staff (primarily coach), and personal motivation were the main reasons to use the NHE program.

Table 1. *Baseline characteristics of the study participants*

Player characteristics (n=264)	Mean (SD)/%
Age (yrs)	26.3 (±3.7)
Football experience (yrs)	19.9 (±4.2)
Field position*	
Forward	29.2% (n=76)
Midfielder	33.5% (n=87)
Defender	34.6% (n=90)
Goalkeeper	12.3% (n=32)
Hamstring injury in previous year	20% (n=52)
Other football injuries in previous year	59.2% (n=154)
Coach characteristics (n=23)	Mean (SD)
Age (yrs)	47.4 (±9.7)
Coaching experience (yrs)	20 (±10)
Medical staff characteristics (n=29)	Mean (SD)
Age (yrs)	45.2 (±11.9)
Medical staff experience (yrs)	18.1 (±10.8)

** Some players had multiple field positions.*

DISCUSSION

This study investigated adherence to an evidence-based hamstring injury prevention program in a real-world context of male amateur football players, and factors perceived by targeted end users (eg, players, coaches, and medical staff) that influence the adherence to the program. The results showed that the majority of the players (69%) did not adhere to the NHE program after a 2-year follow-up, and adherence was higher among players who already had experienced the NHE program in the RCT. Players stated that "personal motivation" and "knowledge of the NHE program" were important factors for adherence. Coaches additionally stated that effectiveness of the NHE program was important, and medical staff considered "consensus with staff" and "motivation of players" as important factors.

Bahr et al.[21] also studied adherence to an NHE program, but in a professional football environment, where adherence to injury preventive measures would be expected to be higher. They investigated the medical staff of 50 professional football teams from Champions League teams and Norwegian premier league teams, where pioneer research on NHEs was performed.[4,5] However, even in a professional environment, adoption of the NHE program was low–only 10.7% of all clubs were adherent with the NHE program.[21] Interestingly, a study on adherence to neuromuscular training aimed at reducing anterior cruciate ligament injury rates in female adolescent football revealed similar results.[25] Despite high effectiveness and adoption, the neuromuscular training program was

Table 2. *Factors that contributed to continued or increased adherence to the NHE program for the prevention of hamstring injuries.*

	Important % (n)	Neutral % (n)	Less Important % (n)
Male football players (n=264)			
Knowledge of NHE	**85** (225)	11 (29)	4 (10)
Personal motivation	**81** (215)	8 (22)	10 (27)
Effectiveness of NHE	74 (194)	21 (55)	6 (15)
Stimulus from coach	54 (143)	19 (51)	27 (70)
Support from board of directors	52 (138)	16 (41)	32 (85)
Match schedule	50 (132)	20 (53)	30 (79)
Other preventive exercises	37 (97)	41 (107)	23 (60)
Time consumption	33 (86)	25 (66)	42 (112)
Football coaches (n=23)			
Effectiveness of NHE	**87** (20)	4 (1)	9 (2)
Personal motivation	**87** (20)	0 (0)	13 (3)
Knowledge of NHE	**83** (19)	17 (4)	0 (0)
Support from board of directors	61 (14)	13 (3)	26 (6)
Match schedule	52 (12)	17 (4)	30 (7)
Time consumption	48 (11)	17 (4)	35 (8)
Motivation of players	44 (10)	9 (2)	48 (11)
Correspondence to training	39 (9)	13 (3)	48 (11)
Other preventive exercises	22 (5)	44 (10)	35 (8)
Medical staff members of football clubs (n=29)			
Personal motivation	**100** (29)	0 (0)	0 (0)
Effectiveness of NHE	**93** (27)	7 (2)	0 (0)
Knowledge of NHE	**86** (25)	14 (4)	0 (0)
Consensus with staff (eg, coach)	**86** (25)	3 (1)	10 (3)
Motivation of players	**79** (23)	14 (4)	7 (2)
Other preventive exercises	59 (17)	17 (5)	24 (7)
Time consumption	55 (16)	7 (2)	38 (11)
Match schedule	48 (14)	10 (3)	41 (12)
Support from board of directors	45 (13)	14 (4)	41 (12)

Bold items indicate a score ≥75%.

only used sporadically, revealing low fidelity to the program protocol.[24] Other studies of adherence or compliance to other preventive measures have also reported poor adherence,[25–27] although it is recognized that the effectiveness of injury prevention strategies is dependent on adherence.[15,18,28–31] While proven effectiveness strengthens athletes' willingness to perform exercise programs,[32] other factors must be important as well because adherence to the NHE program was poor although there is compelling

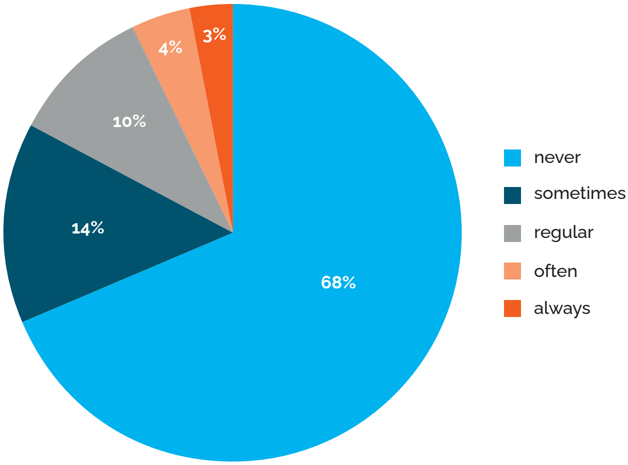

Figure 3. *Adherence to the NHE program.*

evidence of its effectiveness.[4–6] We found that while overall adherence was low, it was higher among players who already had performed the NHE program during the original RCT.

This is in line with the HBM because positive player experiences with the NHE program could have contributed to their perceived benefits of the NHE program. From a practical perspective, this suggests that the supervised introduction of the NHE program could familiarize players with the program and improve adherence. In addition, the role of the team staff (eg, coach and/or medical staff) as the program deliverers and important cue to action for players must be considered. Team staff members are responsible for physical training and if they include injury prevention in their program, players are likely to follow the instructions of the team staff. Therefore, factors that promote team staff to implement the program are also very important if we aim for maximal adherence to NHE, or potentially any other, prevention programs. In addition, it needs to be emphasized that there is a responsibility as well to ensure the proper knowledge transfer and instruction follow- up from coaches to the athletes.

Key factors for all stakeholders to consider when aiming to promote or improve adherence are knowledge of the NHE and personal motivation. However, each stakeholder also mentioned other factors as well. These factors to promote adherence to injury prevention strategies among targeted end users and those who deliver the program need to be considered if we want evidence-based hamstring injury prevention to truly work in the real world. So far, no studies have investigated the relationship between adherence and effectiveness of hamstring injury prevention programs. In a study of team adherence to FIFA 11 exercises and injury risk in Canadian female youth football players,[33] the injury rate among players with high adherence was 57% lower than the injury rate among players with low adherence. However, after adjustment for team, age group, level of play, and injury history, this between-group difference was not statistically significant. Greater understanding is required regarding the relationship between adherence to, and the effectiveness of, injury prevention programs to reduce injuries in a real-world setting.

A strong point of this study is the large number of participants (=264). Moreover, recall bias was limited because standardized and easy-to-remember questionnaires that also focused on the recent past were performed. A dissemination procedure based on the results from the original RCT[6] was used to promote the NHE program. This ensured that participants from the trial, as well as the Dutch football medicine community, were updated on the results of the original RCT. However, there was no additional implementation strategy to ensure adoption in a real-world setting.[6,22] This could have limited adoption and adherence of the NHE program. A weak point of the study was the low response rate (45%), but this is similar to the average response rate (53.7 ± 20.4%) to questionnaires.[34] The study team made intensive efforts to contact all players of the original RCT (n=579) through email, telephone, football club, and social media. However, mostly due to the fact that participating clubs did not have up-to-date contact data of players involved, the research team was unable to contact 295 (51%) of these players. The majority of these players had transferred to other teams; so, contact details were lost. Although low response rates can effect generalizability of study results, this study was still able to reach over 300 stakeholders involved in hamstring injury prevention in amateur football, which is a large sample of participants.[35] Therefore, we do not feel that a higher response would have affected our results and conclusions because the results of this study were derived from a large sample of intended end users, and professional football data show similar results.[21]

The practical implication of our findings is that factors such as personal motivation, experience and knowledge need to be considered when stimulating adherence to hamstring injury prevention programs. Nordic hamstring exercise adherence was higher among players who were familiar with the program. Thus, it is important to take the time to familiarize players and coaches with the NHE program. Players need knowledge of the NHE program and motivation, and coaches additionally required proof of the effectiveness of the program.

Future studies, specifically on injury prevention in a football setting, should aim to investigate how the key factors for adherence reported by the intended end users and program deliverers can be translated into strategies to support the successful implementation of injury prevention programs.

CONCLUSIONS

Adherence among high-level male amateur football players to the NHE program was very low. Adherence in the intervention group was better than in the control group, suggesting that experience with the program is relevant. Personal motivation of each stakeholder (eg, player, coach, medical staff), knowledge of the NHE program, effectiveness of the NHE program, and consensus between staff members need to be stimulated to improve adherence. Only if these conditions are met, will the NHE program be effective in preventing acute hamstring injuries in a real-world setting.

PERSPECTIVE

This study encompasses some clear messages for clinical practice: (1) adherence among high-level male amateur football players to the NHE program is very low, too low to expect an effect on hamstring injury prevention in a real-world setting; (2) practical experience with the NHE program is relevant to enhance adherence; and (3) personal motivation of each stakeholder (eg, player, coach, and medical staff), knowledge of the NHE program, effectiveness of the NHE program, and consensus between staff members need to be stimulated to improve adherence. Only then can effective hamstring injury prevention lead to an actual hamstring injury reduction in the real-world amateur football setting. Furthermore, great attention is given in the scientific community to hamstring injury research, and many studies on effective preventive measures (such as Nordics) have gained global interest. However, there is much debate about adherence to these exercises, and our findings contribute to this gap in the scientific landscape, aiming to contribute to a framework where evidence-based hamstring injury prevention will be adopted in a real-world setting and actually lead to a hamstring injury reduction.

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4

The effects of lower extremity plyometric training on soccer-specific outcomes in adult male soccer players: A systematic review and meta-analysis

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ABSTRACT

Background: Plyometric training is a specific form of strength training that is used to improve the physical performance of athletes. An overview of the effects of plyometric training on soccer-specific outcomes in adult male soccer players is not available yet.

Purpose: To systematically review and meta-analyze the effects of plyometric training on soccer-specific outcome measures in adult male soccer players and to identify which programs are most effective.

Methods: PubMed, Embase/Medline, Cochrane, PEDro, and Scopus were searched. Extensive quality and risk of bias assessments were performed using the Cochrane ROBINS 2.0 for randomized trials. A random effects meta-analysis was performed using Cochrane Review Manager 5.3.

Results: Seventeen randomized trials were included in the meta-analysis. The impact of plyometric training on strength, jump height, sprint speed, agility, and endurance was assessed. Only jump height, 20-m sprint speed, and endurance were significantly improved by plyometric training in soccer players. Results of the risk of bias assessment of the included studies resulted in overall scores of some concerns for risk of bias and high risk of bias.

Conclusion: This review and meta-analysis showed that plyometric training improved jump height, 20-m sprint speed, and endurance, but not strength, sprint speed over other distances, or agility in male adult soccer players. However, the low quality of the included studies and substantial heterogeneity means that results need to be interpreted with caution. Future high-quality research should indicate whether or not plyometric training can be used to improve soccer-specific outcomes and thereby enhance performance.

Keywords: plyometric exercise, football, football-specific outcomes, performance, sprint speed

INTRODUCTION

Soccer consists of repeated high-intensity activities,[1] such as sprinting, jumping, and changing direction,[2,3] and requires players to have excellent strength and endurance to cope with the physical demands of the game.[1-3] A specific form of strength training that is used widely in team sports to meet these demands and improve physical performance is plyometric training.

Plyometric exercises are characterized by explosive muscle extension and contraction and are thought to improve neural efficiency.[4] These specific exercises consist of 3 phases: (1) the (eccentric) pre-activation phase, (2) the (isometric) amortization phase, and (3) the (concentric) shortening phase.[4] In the eccentric pre-activation phase, the Golgi tendon organs are stretched more than in regular strength training. This leads to a greater inhibition of the protective function of the Golgi tendon and a greater concentric power output.[4,5] In other words, plyometric training can strengthen the elastic properties of connective tissue, improve the mechanical characteristics of the muscle–tendon complex, and optimize cross- bridge mechanics and motor unit activation.[6,7] These adaptations are associated with increased joint stiffness, improved muscle strength, increased contraction speed, and improved dynamic stability and neuromuscular control.[5-7] Consequently, these exercises might increase jump height, sprint speed, agility, and endurance.[8]

Several studies have focused on effects of plyometric training programs on sport-specific outcomes. Most of these studies assessed sprint speed, jump height, agility, and endurance in a variety of sports and age categories.[4,6,9,10] Soccer differs significantly from other intermittent team sports because of the rules of the game and field size. This results in unique game demands illustrated by the high number of sprints over both short and long distances, time in high-velocity running, duration of low-intensity activity, number of jumps, and long duration of matches.[11,12] Because of the different intensity and demands of soccer relative to other team sports, physical capacities of soccer players might be different compared with other team-sport athletes. As physical capacities are key factors in effects of training interventions, and plyometric training is mostly added to regular sport-specific training, it is unclear how the results of earlier studies can be generalized to adult male soccer players. Moreover, a better insight into the characteristics of these interventions (training dose) is needed to determine which programs are most effective. Therefore, the aim of this study was to systematically review and meta-analyze the effects of plyometric training on soccer-specific outcomes in adult male soccer players and to determine which programs seem to be most effective.

METHODS

Study design and registration

PubMed, Embase/Medline, Scopus, PEDro, and Cochrane data- bases were systematically searched for articles describing the soccer- specific effects of plyometric training in adult players. Sport-specific outcomes included sprinting, jumping, agility, strength, repeated-sprint ability, and endurance. This systematic review follows the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines and was registered in the international prospective register for systematic reviews (PROSPERO) with reference number CRD42019082664 on February 1, 2019.[13,14]

Search strategy and study selection

Keywords related to the population (ie, male soccer players); type of training (ie, plyometric exercises, bounding exercises); and sport- specific outcomes (ie, strength, jumping, and sprint speed) were used. (The search string is provided in Appendix A.) The databases were searched for articles published up to February 1, 2019. Two researchers (P.A.H. and J.J.B.) independently screened titles and abstracts to identify articles meeting the inclusion criteria described below. The full text of the selected articles was retrieved and independently screened by the same researchers to determine whether articles met the inclusion criteria. The reference lists of the included articles were checked to ensure no publications were missed by the initial search.

Inclusion and exclusion criteria

Plyometric training in soccer players is mostly incorporated in regular soccer training. To assess the additional benefit of plyometric training on regular soccer training, studies were included if they met the following 3 criteria: (1) focused on adult male soccer players; (2) compared a plyometric training intervention with a control group or another intervention; and (3) described soccer-specific outcome measures (ie, strength, jumping, sprinting, agility, or endurance). All nonrandomized studies, qualitative studies, reviews, and cross- sectional studies were excluded, as were articles not written in English, articles that were not available in full text, articles with only sprint training as intervention, and articles studying acute post-exercise effects. Articles were excluded when insufficient data were reported to allow meta-analysis, and additional data could not be retrieved by contacting the corresponding authors. Data were considered insufficient if postintervention means and SDs were not reported or the results were reported only in graphical form. When studies compared 3 or more groups, we only compared the plyometric training group with the "regular training group."

Quality assessment and risk of bias assessment

Two authors (P.A.H. and J.J.B.) independently performed quality and risk of bias assessments for the included studies. Cochrane Robins 2.0 for randomized trials was used.[15] This tool assesses methodological quality and indicates a potential risk of bias on the basis of 6 aspects: (1) randomization process, (2) effects of assignment to intervention, (3) effects of adherence to intervention, (4) missing outcome data, (5) risk of bias in measurement of the outcome, and (6) risk of bias in the reported results. The overall judgement was summarized as "low risk of bias," "some concerns," or "high risk of bias." The publication bias assessment is visualized in a funnel plot per outcome measure. If the 2 assessors did not agree about article selection, quality assessment, or risk of bias assessment, consensus was sought in a meeting. If necessary, the fifth author (M.S.B.) was consulted to make the final decision.

Data extraction and data synthesis

A standardized data extraction form was developed consisting of the name of the first author; year of the publication; study design; number and description of the participants; type of intervention; training frequency, intensity, and duration of the intervention; control intervention; the type of measurements; and reported effect sizes. Meta-analysis was performed on the extracted data using Cochrane Review Manager (RevMan) [computer program] (version 5.3; The Nordic Cochrane Centre, The Cochrane Collaboration, 2014, Copenhagen, Denmark).[16] Heterogeneity was checked using a random effects meta-analysis model; effect sizes and the I^2 statistic were calculated.

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When different instruments were used to measure the same outcome, performance tests were matched based on distances, number of repetitions, and directional changes. When the outcomes of sprint tests were reported as an average speed, this was converted to time to complete the test. For agility, data from the agility *t* test and the zigzag change of direction (zigzag COD) were combined in the analysis. Strength was measured with double-legged 1 repetition maximum (1RM) test and single-legged 1RM test. The double-legged 1RM test results were pooled in the analysis. The single- legged peak power measurement was excluded because these data cannot be converted to a double-legged 1RM.[17] Due to differences in intervention designs and study protocols, large heterogeneity in the extracted data ($I^2 > 60\%$) was expected.

RESULTS

Literature search

The electronic database search identified 778 articles. A total of 524 duplicates were removed, and the remaining 523 titles and abstracts were screened. The full text of 42 articles was retrieved and assessed for eligibility. Of these 42 articles, 17 articles were included in the analysis (Figure 1). Cohen kappa for title and abstract selection and for full-text selection was 0.75 and 0.67, respectively, indicating substantial agreement between the 2 researchers (P.A.H. and J.J.B.) in article selection.[18]

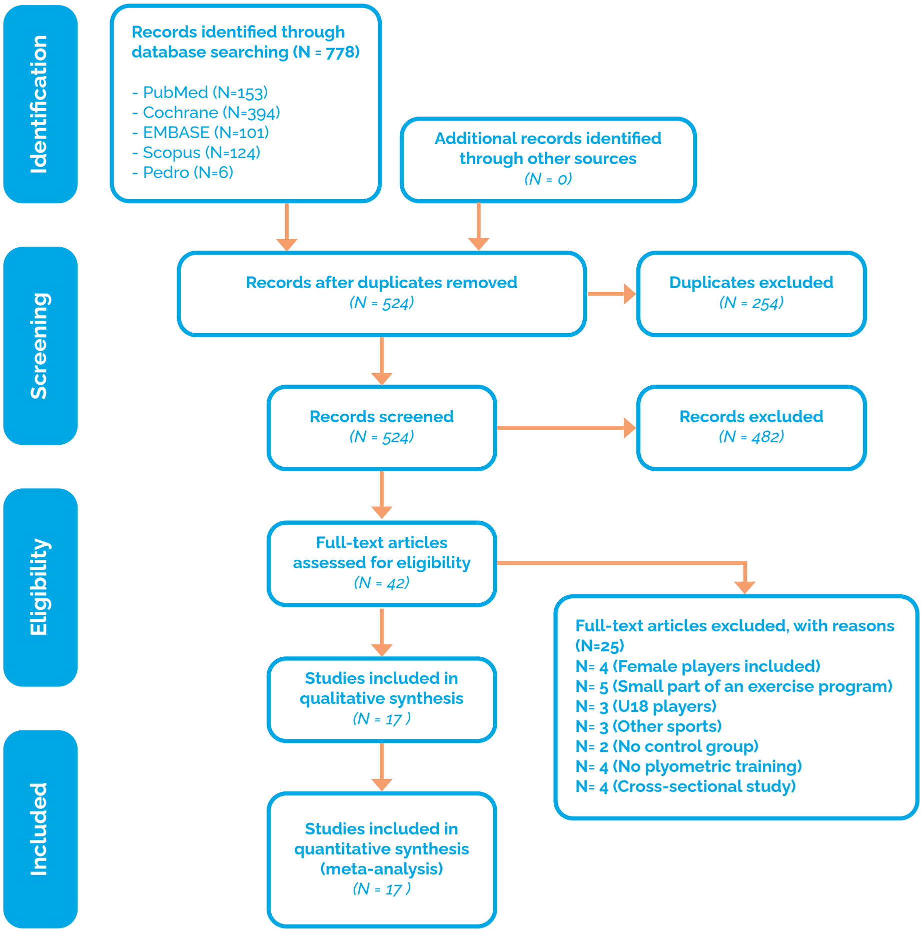

Figure 1 *— PRISMA flowchart*[13]

Study description

The studies included in this review used a variety of plyometric training programs and included soccer players competing at an amateur (N = 3), semiprofessional (N = 5), and professional (N = 9) levels (Table 1). The plyometric training programs varied in frequency, intensity, duration, time in season when given, and mode and sequence of the exercises. Ten of the included studies compared the intervention with regular training. Four of these 10 studies investigated solely a plyometric training program,[23,28,30,32] 4 studies added strength training to the plyometric program,[17,21,22,29] 1 study added sprint training to a complex program,[20] and 1 study investigated a high-intensity intermittent training program.[33]

Table 1. *study demographics*

Authors	Population	Country	Type of training	Duration and intensity	Comparison	Timing of intervention
Arcos et al[19]	Professional soccer players, Male (n=15), Age 20.3 (1.9) y/ 19.6 (1.6) y	Spain	Horizontal and vertical PT + ST	8 wk, 1-2 training sessions/ week of 25-30 minutes, intensity per exercise is set at percentage of peak power or body weight	Vertical PT + ST	Preseason
Boer and van Aswegen[20]	Elite soccer players, Male, (n=46), Age 21.7 (1.8) y	South-Africa	Complex training	6 wk, 3x/wk, 25min/session, 6 reps 80% - 90% of 1RM (resistance training)/ 5m skipping, 8 Jumps. 6 maximum jumps (PT).	No supervised training	Preseason
Brito et al[21]	Amateur (college) soccer players, Male (n=57), Age 19.9 - 20.7 (0.5 - 1.0) y	Portugal	ST+ PT	9 wk, 2x/wk, 15-20min per session	Regular training	In season
Faude et al[22]	Professional soccer players, Male (n=22), Age 23.1 (2.7) y, 22.6 (2.4) y	Switzer-land	ST + PT	7 wk, 2x/wk, 30min	Regular training	In season
Jovanovic et al[23]	Professional soccer players, Male (n=100), Age 19 y, 19 y	Croatia	PT	8 wk, 3x/wk, duration N/A	Regular training	In season
Loturco et al[24]	Professional soccer players, Male (n=32), Age 19.1 (0.7) y, 19.1 (0,7) y	Brazil	PT + ST	6 wk, 2x/wk training program and 4x/wk tactical and soccer-specific training	PT with increased velocity and decreased intensity	Preseason

Table 1. *Continued.*

Authors	Population	Country	Type of training	Duration and intensity	Comparison	Timing of intervention
Loturco et al[25]	Amateur soccer players, Male (n=24), Age 18.7 (0.5) y, 18.4 (0.6) y	Brazil	PT	6 weeks, 2x times/wk N/A	Jump squat training reducing bar velocity by increasing weight	Preseason
Loturco et al[26]	Professional soccer players, Male (n=23), Age23.1 (3.2) y, 23.9 (4.4) y	Brazil	ST + PT	6 weeks, 3x/wk	Optimum power load (OPL) jump squats	Between state first division and Series C National Championships
Loturco et al[27]	Professional soccer players, Male (n=22), Age 21.7 (2.4) y, 22.2 (2.4) y	Brazil	PT	5 wk, 2x/wk training program and 6x/wk tactical and technical training	OPL + Resisted sprint training	Preseason
Mendiguchia et al[17]	Amateur male soccer players, Male (n=60), Age 22.7 (4.8) y, 21.8 (2.5) y	Spain	ST + PT	7 weeks, 2x/week, 30-35 min	Regular soccer training	First half of the season
Nakamura et al[28]	Semiprofessional and regional league collegiate soccer players, Male (n=29), Age 22.9 (2.3) y	Japan	PT	3 wk 2x/wk, 45 min/session, 1 episode of 3 sets square jumps 2x10 jumps (60 jumps total), 1 episode of 3 sets forward bounding 1x16.5m 64 jumps	Regular training	Off-season (post)
Rodriquez - Rosell et al[29]	Semiprofessional soccer players, Male (n=30), Age 24.5 (3.4) y	Spain	ST + PT	6 wk, 2x/wk, 35 min/session, ST progressively increasing from ~45% to 58% of 1RM / PT: not reported	Regular training	In season
Ronnestad et al[30]	Professional soccer players, Male (n=21), Plyo group: Age 23.0 (2) y; ST group: Age 22.0 (2.5) y; Con group: Age 24.0 (1.5)	Norway	ST + PT	7 wks, 2x/wk, plyo: 2-4 sets, 5-10 foot contacts / ST: 4-6 RM with increasing loads, building up from 3 sets to 5 sets	Core training	Preseason

Table 1. *Continued.*

Authors	Population	Country	Type of training	Duration and intensity	Comparison	Timing of intervention
Spineti et al[31]	Semiprofessional (under 20) soccer players (first Brazilian league), Male, (n=22), Age 18.4 (0.4) y	Brazil	Complex/ Contrast training	8 wk, 3x/wk, 3 sequences of 2 sets, CMJ1: 6 reps@60% PP, Frontal jumps: 10x, 40cm height/80cm long, High pull power: 5RM, Sprint: 10m, Knee up +sprint: 5m +10m, Zig-zag: 4x5m, CMJ2: 4 reps@100%pp, single jump on box: 10x, 50cm height, depth "box": 10x 50cm height, depth: 10jumps, 50cm height	ST	In season
Vacsi et al[32]	Semiprofessional (third league) soccer players, Male, (n=24), Plyogroup: Age 21.9 (1.7) y / CG: 22.7 (1.4)	Hungary	PT	6 wk, 2x/wk, 2 wk preparatory, 3 wk increased volume, 1 wk decreased volume to taper. DLHJ: 4x5/6x5/3x5, SLLCJ: 3x10/4x10/2x10, SLFH: 3x5/4x5/2x5, DLDJ: 4x5/6x5/2x5, DLLCJ: 4x5/6x5/2x5, SLHJ: 3x10/4x10/2x10. Total unilateral foot contacts/leg/ session 20-60, Total bilateral foot contacts/session: 20-60	Regular training	N/A
Wells et al[33]	Professional soccer players, Male, (n=16), Age 21.3 (2.1)	N/A	High intensity training	6 wk, 3x/wk, 4-14 sets of 60-10 s > 18kmh	Regular training	In season
Yanci et al[34]	Semiprofessional soccer players, Male (n=21), Age 22.50 (5.04) y, 24.63 (2.72) y	Spain	PT	6 wk, 2x/wk, 360 foot contacts vs 180 foot contacts	PT with half the volume	In season

Abbreviations: CG, control group; CMJ, countermovement jump; DLDJ, double-leg depth jump; DLHJ, double-leg hurdle jump; DLLCJ, double-leg lateral cone jump; PT, plyometric training; SLFH, single-leg forward hop; SLHJ, single-leg hurdle jump; SLLCJ, single-leg lateral cone jump; ST, strength training.

Six studies compared 2 plyometric training programs. Arcos et al.[19] compared a combination of horizontal plus vertical exercises with solely vertical exercises, where the horizontal plus vertical group was considered as the intervention group. Loturco et al.[24-27] compared plyometric programs of different intensities and velocities or power-based loads. The increased velocity groups,[24,25] optimal load group,[26] and the optimum power load plus plyometrics group[27] were considered as the intervention groups. One study[34] compared 2 plyometric programs with different number of repetitions, where the group with the most repetitions was considered as the intervention group.[34] The last study compared a plyometric training program with strength training.[31]

The frequency, intensity, duration, timing, and the design of the intervention differed between the studies. The frequency of plyometric training during the week varied from 2 to 4 times a week. Training intensity was described in terms of number of repetitions, number of acute bouts, number of foot contacts, percentages of maximum strength, frequency of training during the week, and duration of the training. The programs lasted 5 to 9 weeks. The timing of the intervention varied from the preseason (7 studies), in season (8 studies), and off-season (1 study); 1 study did not describe the timing clearly. The mode and sequence of the exercises (design of the program) varied remarkably. The outcomes included in this systematic review and meta-analysis were as follows: strength, jump height, sprint speed, agility, and endurance. No studies evaluating repeated-sprint ability were found.

Strength

Ten studies measured strength as outcome for plyometric training,[17,21,22,24-26,29,30,31,32] assessed with the leg press,[25] dynamometer,[21,22,32] Biodex testing,[17] half squats,[22,30] squats,[21,24,26,29,31] and a custom-built isokinetic dynamometer.[32] We chose to plot the values of overall strength expressed in kilograms (Figure 2). Overall strength was not reported in 1 study,[17] and 1 study did express overall strength in newtons per meter instead of kilograms.[32] Differences in study design and measurements resulted in data heterogeneity. In addition, the risk of bias assessment in combination with the funnel plots indicated a high risk of bias.

Jump height

Eleven studies used the countermovement jump (CMJ) to measure the effects of plyometric training on jump height.[19,21-27,29,30,31] Nine studies were included in this meta-analysis and showed an overall significant effect of an increase of 1.07 cm on the CMJ in favor of the plyometric training programs (1.07, 95% CI, 0.13–2.00) (Figure 3).[19,22,24-27,29,30,31] Two studies did not report data means and SDs, but pre-difference and post-difference in percentages only.[21,23] One of these 2 studies reported the plyometric exercises to have no effect on the CMJ[21] and the other that the exercises significantly improved the CMJ.[23]

Study or subgroup	Experimental Mean (kg)	Experimental SD (kg)	Experimental Total	Control Mean (kg)	Control SD (kg)	Control Total	Weight	Mean difference IV, random, 95% CI (kg)
Faude et al (2013)	170	20.2	8	151.4	24.5	8	13.0%	18.60 (−3.40 to 40.60)
Loturco et al (2013)	107.63	8.29	16	111.44	13.07	16	15.3%	−3.81 (−11.39 to 3.77)
Loturco et al (2015)	187.25	19.74	12	185.5	28.58	12	13.4%	1.75 (−17.90 to 21.40)
Loturco et al (2016)	115.57	8.8	11	115.3	6.7	12	15.4%	0.27 (−6.17 to 6.71)
Rodríguez-Rosell et al (2017)	104.4	17.8	10	91.6	17.9	10	14.2%	12.80 (−2.85 to 28.45)
Ronnestad et al (2008)	220	3	8	183	2	7	15.6%	37.00 (34.45 to 39.55)
Spineti et al (2015)	146.2	21.776	10	155.5	29.4	12	13.1%	−9.30 (−30.72 to 12.12)
Total (95% CI)			75			77	100.0%	8.49 (−10.64 to 27.61)

Heterogeneity: $\tau^2 = 607.97$; $\chi^2 = 209.39$, df = 6 ($P < .001$); $I^2 = 97\%$
Test for overall effect: $Z = 0.87$ ($P = .38$)

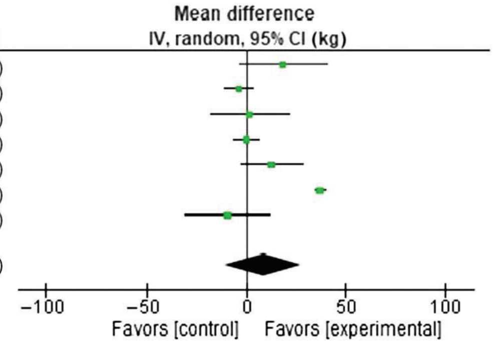

Figure 2 *— Forest plot of strength as outcome measure of plyometric training..*

Study or subgroup	Experimental Mean (height cm)	Experimental SD (height cm)	Experimental Total	Control Mean (height cm)	Control SD (height cm)	Control Total	Weight	Mean difference IV, Fixed, 95% CI (height cm)
Arcos et al (2014)	43.83	6.59	11	44.5	4.07	11	4.2%	−0.67 (−5.25 to 3.91)
Faude et al (2013)	41.4	3.5	8	39.8	2.4	8	10.2%	1.60 (−1.34 to 4.54)
Loturco et al (2013)	41.46	3.71	16	42.56	4.34	16	11.2%	−1.10 (−3.90 to 1.70)
Loturco et al (2015)	39.98	3.99	12	38.11	3.61	12	9.5%	1.87 (−1.17 to 4.91)
Loturco et al (2016)	44.52	3.68	11	44.18	3.05	12	11.4%	0.34 (−2.44 to 3.12)
Loturco et al (2017)	40.6	3.7	11	39.8	3.3	11	10.2%	0.80 (−2.13 to 3.73)
Rodríguez-Rosell et al (2017)	39.8	4.2	10	37	4.2	10	6.5%	2.80 (−0.88 to 6.48)
Ronnestad et al (2008)	36.7	1.9	8	35.7	1.4	7	31.3%	1.00 (−0.68 to 2.68)
Spineti et al (2015)	36.4	4.7	10	31.6	4.9	12	5.4%	4.80 (0.78 to 8.82)
Total (95% CI)			97			99	100.0%	1.07 (0.13 to 2.00)

Heterogeneity: $\chi^2 = 7.71$, df = 8 ($P = .46$); $I^2 = 0\%$
Test for overall effect: $Z = 2.23$ ($P = .03$)

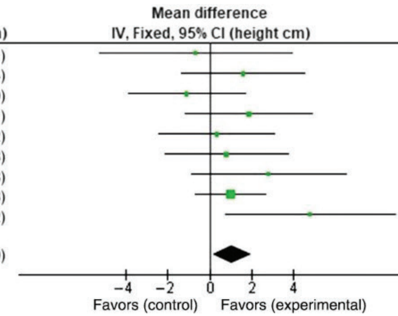

Figure 3 *— Forest plot of jump height as outcome measure of plyometric training.*

4

Sprint speed

Thirteen studies reported sprint time over 5 to 50 m as outcome. The most used distance was 10m,[22,23,24-26,28,29,30] followed by 20m,[21,23,25-27,28,29] 5m,[19,21,23,25,26,28,34] 30m,[20,22,23,24,27] and 40m[30] (Figures 4–8). The data from some studies were incomplete and could therefore not be included in the meta-analysis.[21,23]

Plyometric exercise increased sprint speed over 20 m (Figure 7), but not over the other distances (Figures 4–6, 8). Sprint speed over 40 m was increased in the plyometric training group and the plyometric + strength training compared with the control group, but there was no difference between the plyometric training and the plyometric + strength training groups.[30]

Funnel plots for the 10-m sprint test (Figure 9B) showed a skewed plot, which indicate a potential risk of publication bias.

Agility

Agility was measured with the agility t test and the zigzag change of direction (COD) test. Five studies reported the best time for the tests postintervention,[25-27,32,34] 1 study reported the average time of the 2 best trials,[20] and those results were analyzed in the meta-analysis (Figure 10). The overall effect of these studies showed no improvement by plyometric training on agility. How- ever, funnel plot analysis indicated a potential risk of publication bias (Figure 9G).

Endurance

Six studies investigated the effects of plyometric training on endurance, measured with the Yo-Yo Intermittent Recovery Test 2 (YYIRT2)[20,28,33] and the Yo-Yo Intermittent Recovery Test 1 (YYIRT)[22,34]; 1 study used an endurance running test at selected speeds.[19] Only 4 of the 6 studies reported sufficient data to allow meta-analysis. These studies show that plyometric training improves endurance, measured with YYIRT2 and YYIRT tests significantly (Figure 11).

Nakamura et al.[28] found a smaller decrease in endurance during a detraining period with low-intensity plyometric training than with no training. Arcos et al.[19] showed a significant improvement in endurance with 2 plyometric training programs (vertical and vertical plus horizontal exercises), with no difference between the 2 groups.

Study or subgroup	Experimental Mean (s)	Experimental SD (s)	Experimental Total	Control Mean (s)	Control SD (s)	Control Total	Weight	Mean difference IV, random, 95% CI (s)
Arcos et al (2014)	0.96	0.03	11	0.96	0.04	11	39.3%	0.00 (–0.03 to 0.03)
Brito et al (2014)	0	0	0	0	0	0		Not estimable
Jovanovic et al (2011)	0	0	0	0	0	0		Not estimable
Loturco et al (2015)	1.05	0.04	12	1.05	0.05	12	26.1%	0.00 (–0.04 to 0.04)
Loturco et al (2016)	1.01	0.08	11	1.02	0.06	12	10.1%	–0.01 (–0.07 to 0.05)
Nakamura et al (2012)	1.04	0.06	11	1.06	0.05	5	10.8%	–0.02 (–0.08 to 0.04)
Yanci et al (2016)	1.02	0.06	8	1.02	0.04	8	13.7%	0.00 (–0.05 to 0.05)
Total (95% CI)			53			48	100.0%	–0.00 (–0.02 to 0.02)

Heterogeneity: $\tau^2 = .00$; $\chi^2 = 0.48$, df = 4 ($P = .98$); $I^2 = 0\%$
Test for overall effect: $Z = 0.34$ ($P = .74$)

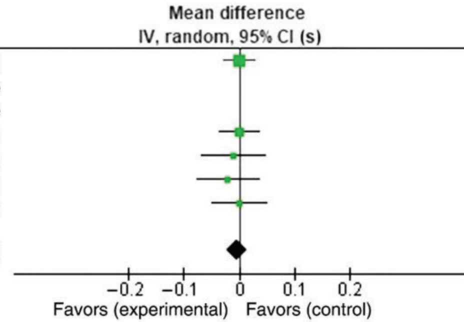

Figure 4 *— Forest plot of 5-m sprint time as outcome measure of plyometric training.*

Study or subgroup	Experimental Mean (s)	Experimental SD (s)	Experimental Total	Control Mean (s)	Control SD (s)	Control Total	Weight	Mean difference IV, random, 95% CI (s)
Faude et al (2013)	1.77	0.05	8	1.77	0.05	8	14.4%	0.00 (–0.05 to 0.05)
Loturco et al (2013)	1.74	0.1	16	1.74	0.1	16	8.3%	0.00 (–0.07 to 0.07)
Loturco et al (2015)	1.78	0.07	12	1.79	0.06	12	13.1%	–0.01 (–0.06 to 0.04)
Loturco et al (2016)	1.66	0.07	11	1.72	0.07	12	11.3%	–0.06 (–0.12 to –0.00)
Nakamura et al (2012)	1.81	0.08	11	1.79	0.08	5	5.8%	0.02 (–0.06 to 0.10)
Rodríguez-Rosell et al (2017)	1.71	0.08	10	1.78	0.06	10	10.0%	–0.07 (–0.13 to –0.01)
Ronnestad et al (2008)	1.74	0.02	8	1.74	0.02	7	37.1%	0.00 (–0.02 to 0.02)
Total (95% CI)			76			70	100.0%	–0.01 (–0.04 to 0.01)

Heterogeneity: $\tau^2 = .00$; $\chi^2 = 8.17$, df = 6 ($P = .23$); $I^2 = 27\%$
Test for overall effect: $Z = 1.26$ ($P = .21$)

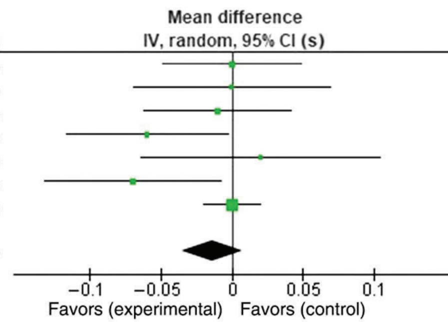

Figure 5 *— Forest plot of 10-m sprint time as outcome measure of plyometric training.*

Study or subgroup	Experimental Mean (s)	Experimental SD (s)	Experimental Total	Control Mean (s)	Control SD (s)	Control Total	Weight	Mean difference IV, random, 95% CI (s)
Arcos et al (2014)	2.29	0.08	11	2.3	0.09	11	56.3%	−0.01 (−0.08 to 0.06)
Yanci et al (2016)	2.3	0.07	8	2.39	0.11	8	43.7%	−0.09 (−0.18 to 0.00)
Total (95% CI)			**19**			**19**	**100.0%**	−0.04 (−0.12 to 0.03)

Heterogeneity: $\tau^2 = .00$; $\chi^2 = 1.86$, df = 1 ($P = .17$); $I^2 = 46\%$
Test for overall effect: $Z = 1.13$ ($P = .26$)

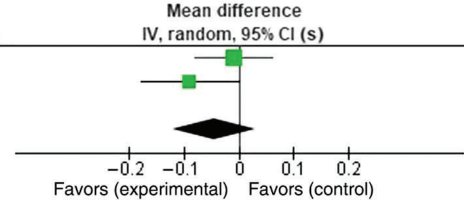

Figure 6 *— Forest plot of 15-m sprint time as outcome measure of plyometric training.*

Study or subgroup	Experimental Mean (s)	Experimental SD (s)	Experimental Total	Control Mean (s)	Control SD (s)	Control Total	Weight	Mean difference IV, random, 95% CI (s)
Loturco et al (2015)	3.01	0.08	12	3.05	0.08	12	52.6%	−0.04 (−0.10 to 0.02)
Loturco et al (2016)	2.9	0.13	11	3	0.16	12	15.3%	−0.10 (−0.22 to 0.02)
Nakamura et al (2012)	3.13	0.13	11	3.1	0.15	5	9.3%	0.03 (−0.12 to 0.18)
Rodríguez-Rosell et al (2017)	2.97	0.14	10	3.06	0.07	10	22.9%	−0.09 (−0.19 to 0.01)
Total (95% CI)			**44**			**39**	**100.0%**	−0.05 (−0.10 to −0.01)

Heterogeneity: $\tau^2 = .00$; $\chi^2 = 2.46$, df = 3 ($P = .48$); $I^2 = 0\%$
Test for overall effect: $Z = 2.29$ ($P = .02$)

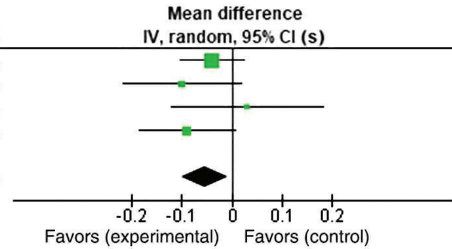

Figure 7 *— Forest plot of 20-m sprint time as outcome measure of plyometric training.*

Study or subgroup	Experimental Mean (s)	Experimental SD (s)	Experimental Total	Control Mean (s)	Control SD (s)	Control Total	Weight	Mean difference IV, random, 95% CI (s)
Boer et al (2016)	4.2	0.2	17	4.2	0.3	13	11.3%	0.00 (−0.19 to 0.19)
Faude et al (2013)	4.27	0.09	8	4.19	0.09	8	51.7%	0.08 (−0.01 to 0.17)
Loturco et al (2013)	4.18	0.14	16	4.17	0.16	16	37.0%	0.01 (−0.09 to 0.11)
Total (95% CI)			**41**			**37**	**100.0%**	0.05 (−0.02 to 0.11)

Heterogeneity: $\tau^2 = .00$; $\chi^2 = 1.26$, df = 2 ($P = .53$); $I^2 = 0\%$
Test for overall effect: $Z = 1.39$ ($P = .16$)

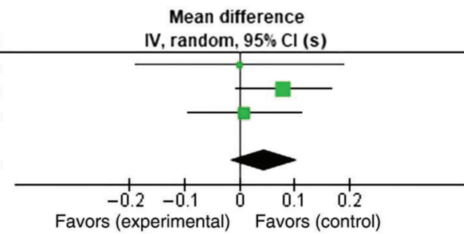

Figure 8 *— Forest plot of 30-m sprint time as outcome measure of plyometric training.*

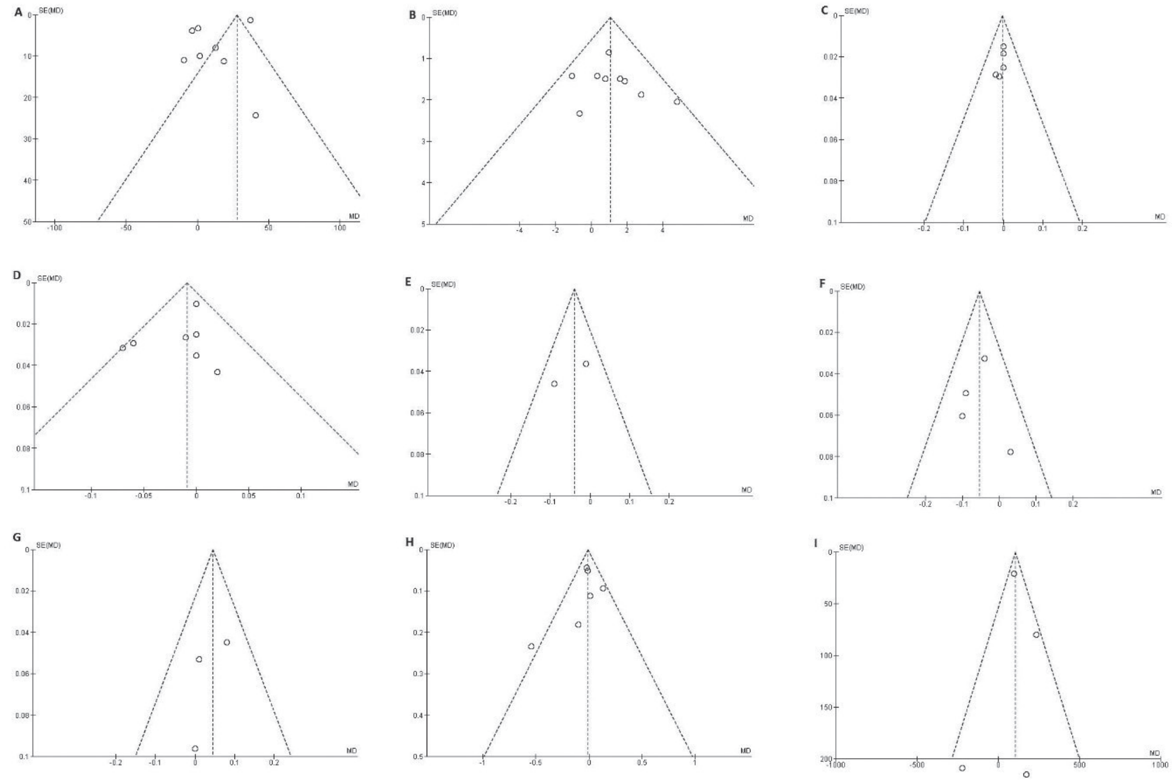

Figure 9 *— Funnel plots per outcome measure. (A) Funnel plot of strength, (B) funnel plot of countermovement jump, (C) funnel plot of 5-m sprint test, (D) funnel plot of 10-m sprint test, (E) funnel plot of 15-m sprint test, (F) funnel plot of 20-m sprint test, (G) funnel plot of 30-m sprint test, (H) funnel plot of agility, (I) funnel plot of endurance.*

Study or subgroup	Experimental Mean (s)	Experimental SD (s)	Experimental Total	Control Mean (s)	Control SD (s)	Control Total	Weight	Mean difference IV, random, 95% CI (s)
Boer et al (2016)	9.3	0.3	17	9.4	0.6	13	5.1%	–0.10 (–0.46 to 0.26)
Loturco et al (2015)	3.58	0.11	12	3.59	0.14	12	30.6%	–0.01 (–0.11 to 0.09)
Loturco et al (2016)	3.63	0.11	11	3.65	0.1	12	34.6%	–0.02 (–0.11 to 0.07)
Loturco et al (2017)	5.91	0.25	11	5.78	0.19	11	15.0%	0.13 (–0.06 to 0.32)
Váczi et al (2013)	15.08	0.36	12	15.62	0.73	12	3.2%	–0.54 (–1.00 to –0.08)
Yanci et al (2016)	4.87	0.2	8	4.86	0.25	8	11.5%	0.01 (–0.21 to 0.23)
Total (95% CI)			**71**			**68**	**100.0%**	–0.01 (–0.10 to 0.07)

Heterogeneity: $\tau^2 = .00$; $\chi^2 = 7.60$, df = 5 ($P = .18$); $I^2 = 34\%$
Test for overall effect: $Z = 0.27$ ($P = .79$)

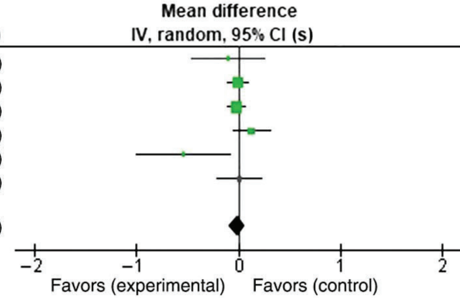

Figure 10 *— Forest plot of agility as outcome measure of plyometric training.*

Study or subgroup	Experimental Mean (distance m)	Experimental SD (distance m)	Experimental Total	Control Mean (distance m)	Control SD (distance m)	Control Total	Weight	Mean difference IV, random, 95% CI (distance m)
Boer et al (2016)	741.8	242.8	17	507	196.2	13	29.2%	234.80 (77.65 to 391.95)
Faude et al (2013)	2,210	326	8	2,429	493	8	7.3%	–219.00 (–628.56 to 190.56)
Wells et al (2014)	987	44	8	888	42	8	56.6%	99.00 (56.85 to 141.15)
Yanci et al (2016)	2,434	234	8	2,260	561	8	6.9%	174.00 (–247.21 to 595.21)
Total (95% CI)			**41**			**37**	**100.0%**	120.74 (3.00 to 238.49)

Heterogeneity: $\tau^2 = 5918.00$; $\chi^2 = 5.20$, df = 3 ($P = .16$); $I^2 = 42\%$
Test for overall effect: $Z = 2.01$ ($P = .04$)

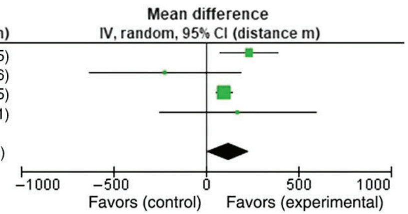

Figure 11 *— Forest plot of endurance as outcome measure of plyometric training.*

Risk of bias assessment

Risk of bias assessment showed a high risk of bias in 10 of the 17 included studies. The other 7 studies scored "some concerns" in the risk of bias assessment (Table 2). The detailed results are added to Appendix B.

Funnel plots were made for each outcome, using Cochrane Review Manager 5.3. Visual interpretation suggested publication bias with regard to strength, jump height, 10-m sprint, and agility outcomes.

Table 2. *Risk of bias overall judgement*

Study	Risk of Bias
Arcos et al., (2013)	High risk
Boer et al., (2016)	Some concerns
Brito et al., (2014)	High risk
Faude et al., (2012)	High risk
Jovanovic et al., (2011)	High risk
Loturco et al., (2013)	High risk
Loturco et al., (2015)	High risk
Loturco et al., (2016)	Some concerns
Loturco et al., (2017)	High risk
Mendiguchia et al., (2015)	Some concerns
Nakamura et al., (2012)	Some concerns
Rodriguez-Rosell et al., (2017)	Some concerns
Ronnestad et al., (2008)	High risk
Spineti et al., (2015)	High risk
Vacsi et al., (2013)	Some concerns
Wells et al., (2014)	Some concerns
Yanci et al., (2016)	High Risk

** When a study scores '+' on all subdomains, the overall judgement is 'low risk of bias'. When a study scores '?'on one or more subdomains the overall judgement is 'some concerns'. When a study scores '-' on one or more subdomains, or '?' on multiple subdomains that results in substantial doubt of the quality of the research, the overall judgement is 'high risk of bias'.*

DISCUSSION

This systematic review and meta-analysis focused on the effects of plyometric training on soccer-specific outcomes. There was evidence for significant benefits on jump height, 20-m sprint speed, and endurance, but an absence of evidence for positive effects on strength, sprint speed over other sprint distances, and agility tasks was found.

When interpreting the effectiveness of training programs, one should consider both the characteristics of the individuals included in the studies and the training dose that is applied. In this review, 14 out of the 17 studies included (semi)professional soccer players and 3 included amateur soccer players. Given the law of diminishing returns, effects were thus expected to be small and to depend on the training dose.[35]

The training frequency in the included studies varied from 2 to 4 times per week for 5 to 9 weeks; sessions lasted 25 to 35 minutes. The exercises were in addition to regular training sessions in all but one study.[28] The intensity and mode of the exercises varied widely. Most programs consisted of jumps with or without weights (double- legged, single-legged, and alternate-leg jumps), but also skipping or running drills. Jumps were vertical or horizontal depending on the study aims.

Strength

We did not find plyometric training to affect strength. This was unexpected because plyometric training is known to have a positive effect on motor unit activation, changes in cross-bridge mechanics, neural efficiency, and passive tension of the muscle–tendon complex, all of which are associated with increased strength.[6,9]

One of the explanations for the absence of evidence in this review can be found in the large differences in the plyometric programs that are investigated and the interventions they are compared with. One study that compared plyometric training with strength training presented negative results, which suggests that plyometric training is subordinate to strength training for increasing strength.[31] Three studies compared 2 plyometric programs of which loads or velocity of execution were different. In these individual studies, both groups improved strength, but the comparison of mean differences between programs resulted in a small effect in this meta- analysis.[24-26] All other studies that compared plyometric training or plyometric training plus strength training with regular training resulted in increased strength.[22,29,30,32] This suggests that plyometric training can increase strength, but it depends on what type of training is already performed by the players.

Another explanation for the absence of evidence in this review can be found in the large heterogeneity between studies (I^2 = 97%). For example, studies used different methods to measure strength,[3,17,21,24-26,29-32,34] and the reliability and validity of some of the tests can be questioned.[22,24-26,29-32] The outcome of functional tests, such as half squats, full squats, jump squats, and back squats, is highly dependent on the familiarity of the athlete with the exercises and the quality of performance, and not all studies reported familiarization protocols.[31,34] Only one study used the preferred reference standard, isokinetic strength testing with the Biodex system.[17] They measured concentric and eccentric strength with 60°/s. However, this study was excluded because single-leg strength was assessed, but not double-legged 1RM measurements as in the other studies.

In this systematic review and meta-analysis, no evidence was found for positive effects of plyometric training on increasing strength in soccer players. In individual studies, the largest between-group differences were found when the intensity of plyometric training was increased by increasing weight[22,29,30] or volume[32] progressively during the training period. These training programs lasted 6 to 7 weeks, for 30 minutes per session, and all exercises were vertically oriented.

Jump height

Plyometric training significantly improved jump height, as has also been reported for other team sports such as basketball and handball.[36-38] In these team sports, plyometric training is also known to increase strength, which, in turn, is associated with an increase in jump height during sports and rehabilitation.[39,40]

Nine studies assessed jump height by means of the CMJ, with studies comparing plyometric training with an alternative plyometric training program (N = 5), plyometric training with strength training (N=1), or plyometric training with regular training (N = 3).

The 5 studies that compared 2 plyometric interventions compared horizontal exercises versus vertical exercises or increased velocity versus increased weight. Direction of movement and velocity or weight-guided programs probably influence training outcomes[19,24-27] and need to be considered when interpreting the effectiveness of plyometric training. Specific modifications in plyometric training programs result in adaptations in specific tasks. Thus, it is important to clearly describe not only the training program but also the training carried out by the control group. When both training programs are expected to increase jump height, the between group differences are likely to be smaller, which leads to smaller effect sizes.

Although we found plyometric training to increase jump height measured with the CMJ, the methodological limitations and risk of bias of the studies make it still questionable whether plyometric training is the best type of training to improve jump height.[41] The studies reporting a significant effect on jump height lasted 5 to 8 weeks, which means that a longer program is not necessarily more effective than a shorter program. The included studies incorporated plyometric training minimally twice a week, and 2 studies reported training sessions of 30 to 35 minutes.[22,29] It may be advised to use a combination of vertical- and horizontal- oriented jump exercises instead of only vertical jump exercises. A combination of vertical plus horizontal jump exercises seems to be more effective than solely vertical jump exercises in improving jump height.[19]

Sprint speed

Sprint tests over 5 distances were assessed. Plyometric training significantly increased sprint speed over 20 m but not over other distances (5, 10, 15, and 30 m). The increase in 20-m sprint speed is consistent with findings for other sports, but the absence of evidence for other distances is not.[4,9,10,42]

Plyometric training improves motor unit activation, increases joint stiffness, and increases peak torque and lower-extremity strength. Improved motor unit activation and increased joint stiffness improve acceleration,[43] and lower-extremity strength is strongly associated with maximum sprint speed.[44] Therefore, an increase in sprint speed over 20 m and longer distances would be expected. However, peak torque is also strongly associated with explosive short sprints,[8,44] and for this reason, we would have expected to find an increase in sprint speed over short distances (5–15 m). These arguments cannot explain why plyometric training did not improve sprint speed over all distances, but it is possible that sprint speed over both short and long distances require specific training methods.[5]

In the included studies, both short- and long-distance sprint speeds were evaluated after exposing players to one plyometric training program. Considering specificity of training as an important factor, one could hardly expect increased sprint speed over both short- and long-distance sprint speeds while the intervention focuses on short- or long-distance speed improvement. In order to increase soccer performance, players need to improve both short- and long- distance sprint speeds. Although the average distance of sprints in soccer is 15 m, soccer players also need to excel in sprinting over longer distances.[11] Both improving short- and long-distance sprint speeds might require specific training methods.[5,11,44,45]

Absence of evidence for increased sprint speed can also be explained by the various interventions in the control groups that limit contrast. Four of the 5 included studies in the analysis of 5-m sprint speed compared 2 plyometric programs with each other[19,25,26,34] and one study investigated the differences in effect of plyometric training versus no training in a detraining period.[28] For the 10-m sprint speed, 3 studies compared plyometric training with regular training that did not differ significantly,[22,28,30] 1 study that compared plyometric training plus strength training with regular training did significantly improve 10-m sprint speed,[29] and 3 studies compared 2 plyometric training programs.[24-26] Only 2 studies used a 15-m sprint test for evaluating sprint speed after plyometric training and both compared 2 plyometric programs and resulted in an improvement of sprint speed over 15-m, but not enough to be statistically significant different.[19,34]

Finally, the content of the training programs, in which the interventions were embedded, can be a reason for the absence of evidence. Soccer training generally consists of playing soccer, which requires players to sprint, change of direction, and jump frequently.[11,12] Adding 2 to 3 times per week 25 minutes of plyometric training might not be enough to reach overload. The results of this meta-analysis point in the direction that a plyometric program for 6 weeks, 2 times per week with sessions of 30 minutes seemed to be effective in increasing sprint speed over 20 m, but the exact training dose that is needed to gain effect is not clear yet.[25,26,29] Although the mode of exercises varied considerably, 2 studies indicated that an increase in velocity of performance of exercises was more beneficial than increasing weight or resistance of exercises.[25,26] One study added strength training to plyometric training, which resulted in a remarkable increase in sprint speed over 10 m.[29]

Agility

We did not find plyometric training to improve the agility of male soccer players, assessed with the zigzag COD and agility *t* tests. Agility is largely correlated with sprint speed over short distances, and plyometric training is associated with short and explosive movements.[7] Thus, it would seem logical that agility would be improved by plyometric training.[4] Although acceleration and maximum sprint speed only predicted 12% and 20% of the agility performance respectively,[46] studies involving young athletes or other sports have found these exercises to improve agility.[7,47]

Nonetheless, at this point, an absence of evidence is found for effectiveness of plyometric training on agility tasks in adult male amateur soccer players. In previous studies, effects on agility performance caused by plyometric training were found, but these interventions were evaluated in tennis players, baseball players, or college students.[7] The demands on those athletes are different than those on soccer players, which implicates that their regular training sessions and their physical capacities are not comparable with soccer players. In training interventions, physical capacities at baseline and the content of regular training sessions are determining factors in effectiveness of the intervention.[41]

Absence of evidence for effects of plyometric training on agility performance is consistent with the lack of effect on sprint speed over short distances. The agility task consists of short sprints and changing direction, and we found an absence of evidence that plyometric training affected sprint speed over 5 to 15 m. Thus, at the moment, plyometric training cannot be recommended as means to improve agility.

A difficulty in the pooled analysis of the effects of plyometric training on agility is that several tests were used to measure agility. In this study, the zigzag COD and agility *t* test were included.

No advice in designing a plyometric training program can be extracted from this literature review.

Endurance

We found plyometric training to significantly improve endurance. Endurance performance depends on aerobic and anaerobic capacity and neuromuscular factors.[48] Plyometric training aims to improve neuromuscular factors and is known to improve joint stiffness and muscle strength in players of team sports,[4,6] which, in turn, leads to improved running economy.[43,48] In addition, plyometric training has shown to decrease energy cost in running which could lead to better endurance.[49]

The results of this analysis seem contradictory with the results of the sprint speed analysis. When plyometric training only affects running economy by improving neuromuscular control, muscle strength, and joint stiffness, then both running endurance and sprint speed should be positively affected. As for all outcomes in this study, physical capacities must be mentioned as an argument. Soccer players need to have good endurance, but more importantly, it is an interval sport. In soccer, the largest part consists of walking and jogging, and a relative small part consists of sprinting.[11] Thus, the intermittent activity in plyometric training in combination with regular training might create overload and explains why soccer players improved endurance and not sprint speed over all distances. The exact mechanism of why plyometric training benefits endurance performance remains unclear. Many factors affect endurance performance, such as maximum oxygen uptake, anaerobic work capacity, and lactate threshold.[7,48]

Only 4 studies were included in this meta-analysis, they all showed heterogeneity, and there were some concerns of bias or a high risk of bias. Therefore, the results need to be interpreted with caution.

Three of the 4 studies showed benefits of plyometric training on endurance.[20,33,34] In the study that did not report benefits of plyometric training on endurance, both groups improved endurance, but a higher postintervention score on the YYIRT2 was seen in the control group. An explanation for not finding positive results in this study can be that at baseline, the control group scored better on endurance than the intervention group.[22] In this meta-analysis, only the posttest results are included, this is based on the assumption that the groups are similar due to the randomization process (in randomized-controlled trials).

Although the results must be interpreted with caution, based on these studies, a plyometric program to improve endurance should have 2 to 3 sessions of minimally 25 minutes per week for at least 6 weeks. According to the included studies, sessions should include 360 foot contacts or 4 to 14 sets of 10 to 60 seconds duration.[20,33,34]

Strengths and limitations

The results of this systematic review and meta-analysis can be easily implemented in daily soccer practice, because it only included male adult soccer players. Due to field measurements and rules of the game, soccer requires tasks as sprinting over several distances, jumping, agility, and quick COD, lower-extremity strength, and endurance. This meta-analysis included all these outcomes in solely soccer players. An extensive risk of bias assessment was performed using Cochrane Robins 2.0 tool, and unfortunately, all included studies showed some concerns of bias or high risk of bias. Methodological limitations were seen in all domains of Cochrane Robins 2.0 risk of bias assessment tool. This is a major concern in training studies and hinders innovation and implementation of plyometric training.[41]

One of the limitations is that we included studies that compared plyometric training with alternative training programs, such as strength training or sprint training. This may have resulted in smaller differences in effect sizes and thus absence of evidence for most of the soccer-specific outcomes. However, an important advantage is that placebo effects can be ruled out by comparing plyometric training with other types of training. Another limitation is that plyometric training in team sports is rarely done in isolation. The amount of plyometric training in relation to regular training might make it impossible to determine the actual contribution of plyometric training on the soccer-specific outcomes.

The studies also used different tests to measure the same outcomes. Because of differences in psychometric values and test protocols, pooling of these results was not always possible, and some studies were excluded from the meta-analysis.

Finally, although meta-regression analysis could have been performed to correct for the heterogeneity of the data, we chose not to do this because of possible bias and outcomes of the analysis. Concerns about the risk of bias and the low to moderate quality of the included studies mean that the generalizability and possibilities to implement the results of the meta-analysis are limited.

Future research

Methodological quality should improve in future studies focusing on the effects of plyometric training on outcomes related to soccer performance. Studies should include a clear description of the randomization process, the intervention, and the control group. Furthermore, consensus about how results should be presented is needed, with minimally player characteristics and postintervention means and SDs being reported.

Second, research should focus on differences in effects of plyometric exercise modes for soccer-specific outcomes and on investigating which training loads result in the largest response. Furthermore, research should differentiate between vertical and horizontal plyometric exercises and investigate which direction (or combination of directions) is more effective for a specific task.

Another aspect worth investigating is whether plyometric training should be incorporated in injury prevention strategies. The combination of physiological and biomechanical changes caused by plyometric training and possible performance enhancement might make plyometric training suitable for injury prevention strategies and make it easier to implement injury prevention programs in daily soccer practice.

PRACTICAL APPLICATIONS

Coaches and practitioners can use plyometric training for increasing jump height, increasing sprint speed over 20-m, and improving endurance. The key points in designing plyometric training programs were that effective programs consisted of 2 to 3 sessions per week of 25 to 35 minutes each, for a period of at least 6 weeks. In addition, horizontal- and vertical-oriented exercises are advised as well as an increase in velocity of performance instead of an increase in weight of the plyometric exercises. Whether these improvements actually contribute to match performance remains unclear. Based on this systematic review and meta-analysis, plyometric training is not advised to use for increasing strength, 5-, 10-, 15-, and 30-m sprint speed and improve agility in soccer players.

CONCLUSION

This review and meta-analysis showed that plyometric training can improve jump height, 20-m sprint speed (but not over other distances), and endurance in male adult soccer players. However, the low quality of the included studies and the substantial heterogeneity mean that these findings should be interpreted with caution. An absence of evidence for positive effects of plyometric training on strength, 5-, 10-, and 30-m sprints and agility was found.

There is a lack of high-quality studies investigating the effects of plyometric training on soccer-specific outcomes. Future research should be of high methodological quality and clearly describe the randomization process, design, and intensity of the programs, and report postintervention means and SDs and preferably effect sizes. This high-quality research should indicate whether or not plyometric training can be used for performance enhancement.

COMPLIANCE WITH ETHICAL STANDARDS

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Conflict of interest

Sander van de Hoef, Jur Brauers, Maarten van Smeden, Michel Brink and Frank Backx declare that they have no conflicts of interest relevant to the content of this systematic review and meta-analysis.

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5

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

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ABSTRACT

Background: Hamstring injuries are the most common muscle injury in amateur and professional soccer. Most hamstring injuries occur in the late swing phase, when the hamstring undergoes a stretch-shortening cycle and the hamstring does a significant amount of eccentric work. The incidence of these injuries has not decreased despite there being effective injury prevention programmes focusing on improving eccentric hamstring strength. As this might be because of poor compliance, a more functional injury prevention exercise programme that focuses on the stretch-shortening cycle might facilitate compliance. In this study, a bounding exercise programme consisting of functional plyometric exercises is being evaluated.

Methods: A cluster-randomized controlled trial (RCT). Male amateur soccer teams (players aged 18–45 years) have been randomly allocated to intervention and control groups. Both groups are continuing regular soccer training and the intervention group is additionally performing a 12-week bounding exercise programme (BEP), consisting of a gradual build up and maintenance programme for the entire soccer season. The primary outcome is hamstring injury incidence. Secondary outcome is compliance with the BEP during the soccer season and 3 months thereafter.

Discussion: Despite effective hamstring injury prevention programmes, the incidence of these injuries remains high in soccer. As poor compliance with these programmes may be an issue, a new plyometric exercise programme may encourage long-term compliance and is expected to enhance sprinting and jumping performance besides preventing hamstring injuries.

Trial registration: NTR6129. Retrospectively registered on 1 November 2016.

Keywords: Injury, Prevention, Plyometric exercise, Football

BACKGROUND

Thirty-one percent of all injuries in male soccer players are muscle injuries, which account for 27% of injury- related time off soccer[1,2] and 37% of all soccer-related muscle injuries are hamstring injuries. These injuries can be classified as high-speed running injuries and stretching injuries[1,3,4], with the sprint-type injury being the most common type of hamstring injury in soccer[2-5]. Hamstring injuries also have the highest re-injury rate and are associated with the longest time off play and training (>28 days)[1,2,6]. Although several intrinsic and extrinsic risk factors have been identified, to date the incidence of hamstring injuries has not diminished[6-11].

Sprint-type hamstring injuries mostly occur in the late swing phase[4,5,12,13], when the hamstring muscles are maximally stretched during limb deceleration[4,5,13,16]. In the second half of the swing, the bi-articular hamstring muscles undergo a stretch-shortening cycle[14] . The greatest stretch is seen in the femoral biceps, which is the hamstring muscle most often injured[3,5,13,14]. The stretched hamstring muscle actively contracts in the swing phase, which could indicate that the hamstrings contract eccentrically in the late swing phase[13]. In addition, it has been found that as the sprint speed increases, so too does the amount of stretch and negative work of the hamstring muscles[13]. Thus it has been suggested that increasing eccentric strength might reduce the risk of sprint-type hamstring injury.

Recent studies have shown that improving eccentric hamstring strength by means of the Nordic Hamstring Exercise (NHE) can reduce the incidence of hamstring injuries by 66–70%[16,17]. Yet the incidence of hamstring injuries has not only not decreased in the past 10 years, but has actually increased by 4%[18]. This might be because these exercises are not performed correctly or because compliance is poor. A recent study among Champions league and Norwegian premier league teams confirmed this hypothesis: only 6% of the participating teams performed the NHE according the pre- scribed programme[19]. The same trend has been seen in Dutch soccer players[20], with most teams no longer performing the prevention programme 3 years after its introduction[20]. Arguments for non-compliance mentioned in the Netherlands are lack of time, delayed onset muscle soreness, the need to sit on the ground or a mat, and not sport- specific enough to incorporate into the warming-up[20].

The bounding exercise programme (BEP) is another potentially effective training programme that can be done after warming-up. It consists of single leg jump exercises characterized by a stretch-shortening cycle[21]. The stretch-shortening cycle strengthens the elastic properties of connective tissue, thereby improving (eccentric and concentric) strength and power by allowing the muscle to accumulate (pre-stretch / eccentric phase) and release (concentric phase) energy[22,23]. Specific physiological adaptations induced by plyometric training are increased motor unit activation, increased passive tension of the muscle-tendon complex, and improvement of cross-bridge mechanics[24,25].

These adaptations are associated with improved strength, increased joint stiffness, and improved neuro-muscular control and functional performance[26-28]. Plyometric training is already used widely in intermittent team sports in order to enhance sprinting and jumping performance[22,29-35] and might reduce sprint-type hamstring injuries.

In summary, hamstring injuries are a major health problem in soccer and their incidence has increased over recent years, despite there being effective prevention programmes. This is possibly because of poor compliance. There is an urgent need for a functional, short, easy-to- implement, sport-specific hamstring injury prevention programme that includes eccentric and plyometric exercises, so as to improve the performance of sport-specific tasks, such as sprinting and jumping, and which is likely to be adopted. The BEP could fulfil this need. The aim of this hamstring injury prevention study-3 (HIPS-3) is to investigate the preventive effect of a BEP on hamstring injuries in male amateur soccer players. The secondary aim is to investigate compliance with this programme during the soccer season 2016–2017 and at the start of the soccer season 2017–2018.

METHODS/DESIGN

Design and study setting

This prospective, cluster-randomized trial was designed in accordance with the guidelines of the Standard Protocol Items: Recommendations For Interventional Trials (SPIRIT)[26] . The study is being carried out in cooperation with the University Medical Centre of Utrecht and the Royal Netherlands Football Association (KNVB) in Zeist (the Netherlands). As the BEP is being investigated in a real-life setting, soccer teams from four different districts, playing in Dutch first-class amateur field soccer competition, were invited to participate in this study. These teams usually play one (or two) matches a week, with 2–3 training sessions per week. Each district has two competitions at first-class level.

Recruitment of participants and randomization

Dutch male soccer players (age 18–40 years) playing in the Dutch first-class amateur competition were eligible for participation. All players were asked to give their written informed consent before the start of the study. Players who did not give their informed consent, who joined a team after the start of the study, or who had a lower than average understanding of Dutch were excluded.

After selection of the four districts, a top-down strategy was carried out to recruit the soccer teams. First, the boards of the clubs were informed about the study by means of an email from the director of amateur soccer of the KNVB and the research team. Then the members of the medical staff and the coaches were invited, by telephone, to attend a meeting to tell them about the purpose and methods of this study. If the clubs decided to participate in this study, all players of the participating teams received an information letter including an informed consent form. To avoid a risk of contamination, the teams were randomized as clusters instead of individual players[37]. Randomization was done independently by an online randomizer (https://www.randomizer.org/) and an equal number of teams were assigned to the intervention and control groups. After randomization, meetings were organized in each district to inform staff and players in the intervention group about the BEP.

Intervention

The intervention group is performing the BEP during the entire 2016–2017 outdoor soccer season. In the first 12 weeks, there is a gradual build-up of walking lunges, triplings and drop lunges, and bounding (alternating leg jumps) (Table 1).

Table 1 *BEP Programme*

Week	Programme
1	2x30m walking lunges (2 × 10)
2	3x30m walking lunges (3 × 10)
3	3x30m walking lunges +1x30m triplings + droplunges)
4	2x30m triplings + droplunges (2 × 10)
5	3x30m triplings + droplunges (3 × 10)
6	3x30m triplings + droplunges +1 × 30 m bounding
7	2x20m bounding (+/– 7 jumps)
8	3x20m bounding (+/– 7 jumps)
9	4x20m bounding (+/– 7 jumps)
10	3x30m bounding (+/–10 jumps)
11	4x30m bounding (+/– 10 jumps)
12	4x30m bounding (in the least possible jumps
13 until end of competition	3x30m bounding (in the least possible jumps)

5

This gradual build-up from basic concentric strength exercise to eccentric strength exercise followed by plyometric exercise should improve functional movement patterns and increase strength [38]. All exercises are performed over a distance of 30 m in accordance with the SCORE project, which uses another form of bounding, focusing on vertical stability[39]. After the build-up phase, participants continue with the BEP during warming up in two training sessions and follow a prescribed intensity training programme. After the winter break, when there is no structural training, teams will restart the BEP. In order to compensate for potential de-training effects[40-42], starting with the same programme as performed in week 6. If a player is injured at the start of the programme and recovers from this injury, he re-starts the BEP programme. If a player is injured in weeks 1–6 and achieves full recovery within 4 weeks, he re-starts the BEP at –1 week (i.e. a player injured in week 4 and who achieves full recovery within 4 weeks re-starts the BEP in week 3). If a player is injured in weeks 7–13 and achieves full recovery within

4 weeks, he re-starts the BEP in week 6. If an injury last longer than 4 weeks, the player is asked to contact the research team before resuming the BEP (Table 2).

Table 2. *Restarting BEP after injury*

Week nr. BEP of Injury occurrence	Period of injury (weeks)	Restarting BEP
1–6	<4	Week injury occurrence −1
1–6	>4	Contact with research team
7–13	<4	Week 6
7–13	>4	Contact with research team

Walking lunges (Fig. 1)

The player starts in a standing upright position and steps forward with the right leg. From this position, the left knee moves downwards to the ground while upper body remains upright. This movement is followed by a step forward passing the right foot. From this second position, the right knee moves downwards to the ground, followed by a step forward passing the left foot, etc. It is important that the flexion of the leading knee does not exceed 90 degrees, and that the shoulder, hip, and knee of the back leg are in a vertical line[43].

Figure 1. *Walking lunges.*

Triplings followed by drop lunges (Fig. 2)

Triplings are a classic running exercise. The player starts in a standing position and initiates a fast small step forward and lands on his forefoot, followed by the other leg. This sequence is repeated 4 times. At the same time, the player performs a fast arm swing, After 4 repetitions, the player jumps vertically jump and lands in the end position of the lunge[43].

Figure 2. *Triplings followed by drop lunges.*

Bounding (Fig. 3)

The bounding exercise, in the literature referred to as 'a running bound' or 'alternate leg bounding,' is a popular running-specific exercise that can be categorized as plyometric exercise. These plyometric exercises contain three phases: the eccentric pre-stretch, the amortization phase (time between eccentric and concentric contraction), and the concentric shortening phase[21]. The player starts running and after 3 m he performs horizontal jumps (bounding). The focus of this exercise is to achieve horizontal position of the femur in swing-phase, a full foot landing, and as fast as possible horizontal speed. The running start is chosen to reach a maximum speed in bounding by getting a maximum hamstring musculotendon stretch and force[13]. All players have to cover 30 m excluding the 3 m running start.

Implementation procedures

The medical staff and/or coaches of the intervention teams were instructed how to implement the BEP during the above-mentioned instruction meetings. During these meetings, there was a video presentation of the BEP programme, followed by a live demonstration on the soccer field. Emphasis was on key aspects of the intervention and the performance of the exercises. All coaches and medical staff received the instruction-video and instructions by email and in writing.

Figure 3. *Bounding.*

The research team is always accessible to answer questions by telephone or email. All participating teams are visited, and the medical staff has been asked to record the intervention on camera (cell phone) and to send the recording to the research team for analysis and feedback, at least every 3 weeks in the build-up phase. The BEP is performed at the end of the warming-up. Coaches and medical staff were advised to allow a short active recovery period before the rest of the training session if players complain of tired legs.

Data collection

Baseline characteristics

All participants were asked to complete a questionnaire on baseline characteristics, namely, date of birth, nationality, height, weight, years of experience as a soccer player, field position, leg dominance, preventive measures for hamstring injuries, preventive measures for other injuries, study load/ workload and capacity, hours of sleep, hours of travel, current state of the hamstring muscles in relation to activities, and injury history.

Exposure, injuries, and compliance

Exposure, injuries, and compliance are self-reported weekly throughout the entire soccer season (39 weeks), with players being allowed to choose whether they prefer to register by SMS or by e-mail (NetQ). Each Monday, all players receive four short questions regarding how long they have trained (minutes), how long they have played in a match (minutes), and whether they have had a hamstring injury or another' injury. The players in the intervention group receive a fifth question regarding the amount of BEP they have performed in the past week.

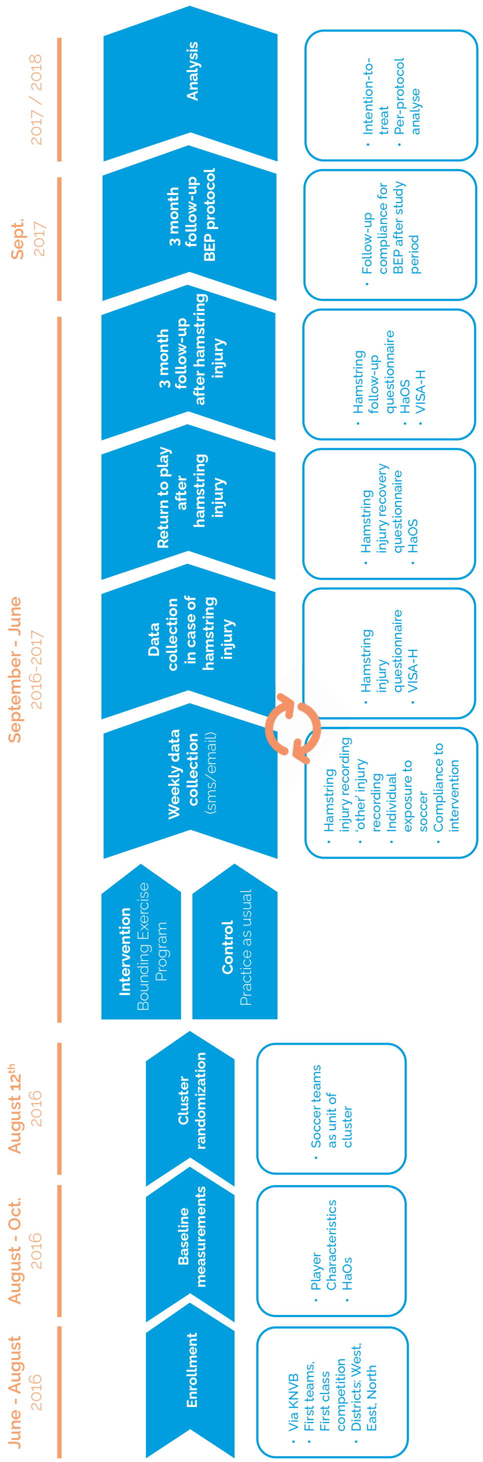

Figure 4. *Study procedure*

	STUDY PERIOD				
	Enrolment	Allocation	Post-allocation		Close-out
TIMEPOINT	*-1 to 3 weeks before competition*	*0*	*Weekly registration*	*End of competition*	*Follow-up measurement 3 months post-intervention*
ENROLMENT:					
Eligibility screen	X				
Informed consent	X				
[Baseline Questionnaire]	X				
Allocation		X			
INTERVENTIONS:					
Bounding Exercise Programme			■————	————■	
Control group			■————	————■	
ASSESSMENTS:					
Demographic data	X	X			
Hamstring injury			X	X	X
'Other injury, Exposure, Compliance to intervention			X	X	X
In case of injury: Hamstring injury questionnaire – RTP questionnaire – 3 Month Follow-up questionnaire			X	X	

Figure 5. *SPIRIT figure.*

Injuries are divided into hamstring injuries, other injuries, and recurrent (hamstring) injuries. A hamstring injury is defined as any physical complaint affecting the posterior side of the upper leg resulting in an inability to play or train regardless of the need for medical attention or time off soccer-associated activities[44]. In the case of a hamstring injury, both the player and the medical staff separately fill in a hamstring injury questionnaire to record epidemiology, severity, and etiology of the injury. Other injuries are defined as any physical complaint, other than affecting the posterior side of the upper leg, that results in an ability to play or train regardless of the need for medical attention or time off soccer-associated activities[44]. Other injuries are recorded for measuring exposure and are not further specified by an injury follow-up questionnaire. Recurrent injuries are defined as an injury of the same type and at the same site as an index injury occurring after a player has returned to full play/training. In the case of a recurrent hamstring injury, the player and medical staff will receive the same hamstring injury questionnaire as for the primary hamstring injury.

Exposure (in minutes) is divided into match play and training sessions. Training exposure is defined as team- based and individual physical activities under the guidance of the team's coaching or fitness staff that are intended to maintain or improve players' soccer skills or physical condition[44]. Match play is defined as a play between two different teams[44].

Intervention compliance is measured weekly by SMS or email (NetQ). The number of metres of the BEP performed is registered as metres/week. Compliance is expressed as a percentage by dividing the meters BEP performed by the metres mentioned in the programme. At the end of the study period, overall compliance will be investigated by means of a self-administered questionnaire.

Long-term compliance with the BEP will be measured once, at the start of the new soccer season 2017–2018. All players in the intervention group will be asked how many metres BEP they performed in that week and how many days ago their last bounding session was (Figs. 4 and 5).

Outcomes

The primary outcomes are the incidence and severity of hamstring injuries. The secondary outcome is compliance with the BEP. The hamstring injury incidence is recorded per 1000 h of exposure, and severity is operationalized as the number of days since the day of injury and the day of full return to play[17]. Compliance is expressed as a percentage of BEP completion.

Sample size

The sample size was calculated based on previous studies. Earlier findings showed a reduction in hamstring injury incidence of up to 70% with eccentric training of the hamstring muscle, an injury incidence of 1 in 11 players per soccer season, and recurrence rates of 12–30%[16,17]. On the basis of these findings and two-sided testing, significance level of 0.05, power 0.8, an inflation correction for cluster randomization of 1.19, drop-out of 20%, and loss to follow-up of 20%, we calculated that 26 teams of approximately 16 players would have to be included. Taking into account that the follow-up period is in a new soccer competition, with a larger loss to follow-up, we included 10% extra players, so that in total the study includes 30 teams with about 16 players/team (n = 480).

Statistical methods

SPSS version 22 will be used to analyse the data. Descriptive statistics will be used to analyse the baseline characteristics. The incidence of hamstring injuries will be analysed on an intention-to-treat basis. The primary outcomes will be compared in the intervention and control groups using Chi-square tests, Poisson general log-linear analysis, and Cox regression analysis with survival curves.

Ethical approval

This trial was approved by the Medical Ethics committee of University Medical Centre of Utrecht (16–332\C) and is registered in the Dutch trial register (http://www.trialregister.nl/trialreg/index.asp) (NTR6129). All participants received a written information letter, and any questions were answered (verbally or in writing) by one of the researchers (SvdH). All participants were asked for their informed consent, and all data are handled according to legal requirements.

DISCUSSION

Hamstring injuries are a major problem in amateur soccer players. Recent studies have shown that a reduction in hamstring injury incidence up to 70% can be achieved by eccentric training following the NHE programme[16,17]. While NHE compliance was high in studies, the NHE programme has not been adopted in amateur soccer and the number of hamstring injuries has not diminished yet[17,18]. Arguments for non-compliance are lack of time, delayed onset muscle soreness, the need to sit on the ground or a mat, and not sport- specific enough to incorporate into the warming-up[19,20].

The BEP, consisting of a gradual build-up to plyometric (bounding) exercises, is a more sport-specific injury prevention programme, so that compliance is expected to be better. It can be easily implemented during warming-up and is expected to improve sprint and jumping performance[29-32].

This study has the advantage of a standardized methodology and consensus regarding definitions of injuries and exposure[44]. The self-reported registration via modern systems, such as SMS and NetQ, will probably ensure valid injury registration and optimal compliance.

ABBREVIATIONS

BEP: Bounding Exercise Programme; HIPS-3: Hamstring Injury Prevention Study-3; KNVB: Royal Netherlands Football Association; NHE: Nordic Hamstring Exercise; SPIRIT: Standard Protocol Items Recommendations For Interventional Trials

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AUTHORS' CONTRIBUTION

SH, BH and FB designed the study in collaboration with NV and EG. SH and MB carry out the study. SH is the main author. All authors, contributed to the manuscript and approved the final version.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study is approved by the Medical Ethics Committee of the University Medical Center Utrecht (16–332\C). All participants included in this study have provided written informed consent to participate.

CONSENT FOR PUBLICATION

The participant in the images has signed consent for publication of the images. The consent form of the University Medical Center Utrecht is signed.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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6

Does a bounding exercise program prevent hamstring injuries in male adult soccer players? – A cluster- RCT

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ABSTRACT

Background: Although the Nordic Hamstring Exercise (NHE) prevents hamstring injury in soccer players effectively, the annual incidence of these injuries still in- creases. This may be because of poor long-term compliance with the program. Furthermore, the timing and amplitude of gluteal and core muscle activation seem to play an important role in hamstring injury prevention, the NHE program was not designed to improve activation of these muscles. Therefore, we propose plyometric training as an alternative to reduce hamstring injuries in soccer players.

Purpose: To determine the preventive effect of the Bounding Exercise Program (BEP) on hamstring injury incidence and severity in adult male amateur soccer players.

Study design: A cluster-Randomized Controlled Trial.

Methods: Thirty-two soccer teams competing in the first-class amateur league were cluster-randomized into the intervention or control group. Both groups were in- structed to perform their regular training program, and the intervention group additionally performed BEP. Information about player characteristics was gathered at baseline and exposure, hamstring injuries and BEP compliance were weekly registered during one season (2016-2017).

Results: The data of 400 players were analyzed. In total, 57 players sustained 65 hamstring injuries. The injury incidence was 1.12/1000 hours in the intervention group and 1.39/1000 hours in the control group. There were no statistically significant differences in hamstring injury incidence (OR = 0.89, 95% CI 0.46-1.75) or severity between the groups ($P > 0.48$).

Conclusion: In this large cluster-randomized controlled trial, no evidence was found for plyometric training in its current form to reduce hamstring injuries in amateur soccer players.

Keywords: bounding exercise, hamstring injuries, injury prevention, plyometric training, soccer

INTRODUCTION

Hamstring injuries are the most common muscle injuries in amateur soccer and account for 15% of all injuries in adult male soccer players.[1,2] The high incidence rate (0.7/1000 soccer hours), together with a high recurrence rate (12%-30%) and long rehabilitation (mean >28 days), makes this injury a major problem in soccer.[1,3,4] Hamstring injuries can be classified as sprint-type injuries and stretching-type injuries, with sprint- type hamstring injuries being the most common in soccer.[1,5] The sprint-type hamstring injury occurs mostly in the late swing phase, when the hamstring undergoes a stretch-shortening cycle.[6,7] In this phase, the hamstring eccentrically contracts to decelerate hip flexion and knee extension. Subsequently, it keeps this position of the hip and knee isometrically and concentrically contracts to accelerate for the next foot step.[6,7]

To prevent this hamstring injury, the Nordic hamstring exercise program is developed. Several studies indicated the preventive effect of this exercise program.[4,12] The Nordic hamstring exercise, by itself or incorporated in an injury prevention program, can reduce the hamstring injury rate when compliance is high.[13] Although effective programs, like these, have been developed to prevent hamstring injuries, the incidence of hamstring injuries in professional soccer players competing in the UEFA is still increasing by 4% annually.[14] As in professional soccer (UEFA), in amateur soccer poor long-term compliance probably limits the effectiveness of interventions such as the NHE.[15,16] Reasons for not performing this effective program are poor knowledge of the (effectiveness of the) program and lack of motivation because the exercises are not specific to soccer (submitted data). Soccer coaches in particular do not consider the NHE as soccer-specific enough.[17] This is a problem in compliance with injury prevention programs in team sports like soccer, since coaches are crucial implementation components.[18]

In addition to the low compliance with injury prevention programs, eccentric strength training might be less effective than plyometric training. Recent studies suggest that the timing of hamstring muscle activation and the timing and amplitude of gluteal and abdominal muscle activation are important for preventing hamstring injuries. Both can be improved by plyometric exercises.[19,20] These exercises strengthen the elastic properties of connective tissue, increase motor unit activation, increase passive tension of the muscle-tendon complex, and improve cross-bridge mechanics.[21,22] This improves eccentric strength, joint stiffness, and neuromuscular control, all variables associated with the occurrence of hamstring injuries.[23,24] Therefore, a new functional, soccer-specific program was developed to reduce hamstring injuries, the bounding exercise program (BEP).[26] The BEP aims to improve long-term compliance and increase both eccentric strength and neuromuscular control. The BEP consists of a gradual build-up from concentric, eccentric to plyometric exercises that can easily be incorporated in regular soccer training and which can be performed individually. The exercises are focused specifically on the late swing phase, during which most hamstring injuries occur, and accentuate the horizontal speed to cause optimal loading of the hamstring muscle.[26] Plyometric exercises also increase functional performance in tasks common to soccer, such as sprinting and jumping. This might increase implementation of the program in regular training, thereby potentially increasing compliance.[27,28] As little is known about the effectiveness of the BEP, the aim of this study was to assess the preventive effect of a functional, soccer-specific BEP on the incidence and severity of hamstring injuries in adult male amateur soccer players.

METHODS

The design of this prospective cluster-randomized controlled trial has been described extensively in the research protocol.[26]

Study setting

This study was carried out in close collaboration with the FIFA Medical Center, Royal Netherlands Football Association (KNVB). In this prospective, cluster-randomized controlled trial, the BEP was investigated in a real-world context among male amateur soccer players in the first-class amateur league. On average, players have two training sessions and one match a week during the 39-week soccer season. This study design was approved by the Medical Ethics Committee of the University Medical Center Utrecht (16-332\C), registered in the Dutch Trial Registry (NTR6129) and was partly funded by The Netherlands Organization for Health Research and Development (ZonMw), and the KNVB.

Eligibility criteria

Male amateur soccer players aged 18-45 years and playing in a first-class league soccer team were eligible to participate in this study. Players who were injured at the start of the study participated from the moment they returned to play. All players received a patient information letter and signed an informed consent before the start of the study. Players who joined the team after the start of the 2016-2017 season could not participate in the study.

Randomization procedure

Randomization was done by a cluster-randomization procedure. All teams were considered as clusters to avoid a risk of contamination between the players within a team.[30] Teams were randomized independently by an online randomizer (https://www.randomizer.org/), and an equal number of teams were assigned to the intervention and control groups.

Intervention

The bounding exercise program (BEP) is a 12-week build-up program (concentric to eccentric to plyometric exercises) and a maintenance program that takes approximately

Table 1. *Bounding exercise program*

WEEK	PROGRAM
1	2x30m walking lunges (2x10)
2	3x30m walking lunges (3x10)
3	3x30m walking lunges + 1x30m triplings + droplunges)
4	2x30m triplings + droplunges (2x10)
5	3x30m triplings + droplunges (3x10)
6	3x30m triplings + droplunges + 1x 30m bounding
7	2x20m bounding (+/- 7 jumps)
8	3x20m bounding (+/- 7 jumps)
9	4x20m bounding (+/- 7 jumps)
10	3x30m bounding (+/-10 jumps)
11	4x30m bounding (+/- 10 jumps)
12	4x30m bounding (in the fewest possible jumps)
13 UNTIL END OF THE SOCCER SEASON	3x30m bounding (in the fewest possible jumps)

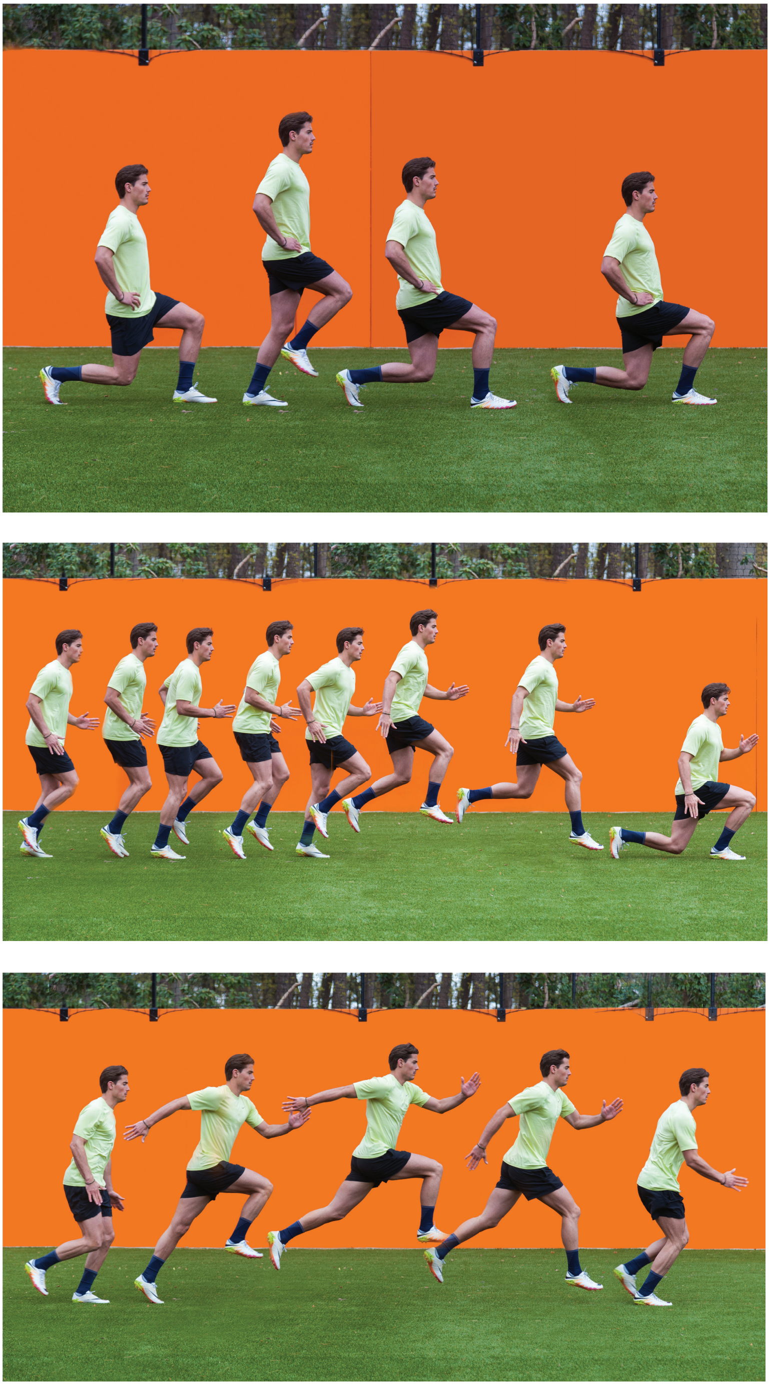
3-5 minutes to complete.[26] The intervention group performed the BEP (Table 1 and Figure 1A,B,C) in addition to their regular soccer training. After randomization, all coaches and medical staff of the included soccer clubs attended a workshop in their area to practice how to instruct players to perform the exercises, in order to ensure high-quality performance of the BEP. The control group performed their usual soccer training. Two researchers visited all participating teams to answer questions and monitor the BEP in the intervention group.

Data collection

Weekly, every player received four or five questions (control or intervention group, respectively) regarding the incidence of hamstring and other injuries, training and match exposure, and compliance with the program (intervention group only). All players could choose to receive the questions by email or short message service (SMS). If a time-loss hamstring injury[31] occurred, the player and medical staff received an additional questionnaire by email regarding the type, location, timing, and occurrence of injury.

Outcomes

The primary outcomes were the incidence of hamstring injuries per 1000 soccer hours and the severity of these injuries. The secondary outcome was compliance with the BEP, calculated as the meters performed divided by total number of meters they performed during regular competition times 100%. The compliance for BEP is measured per player.



a)

b)

c)

Figure 1. *a) Walking lunges. b) Triplings and droplunges. c) Bounding*

Statistical analysis

All data were analyzed with the statistical language and software program "R".[32] Because of a total average of around 50% of missing data points from the weekly self-reports, multilevel multivariate imputation by chained equations was performed to impute missing data for weekly match and training exposure, thereby accounting for the repeated measurement structure of the data, using the mice R-package.[33] Multilevel logistic regression analysis (accounting for the cluster randomization) was performed on imputed data to evaluate and test differences in "any hamstring injury" occurring between the intervention and control groups during the soccer season. Compliance with the program was taken as a covariate in this model. In addition, differences in time-to-first injury between the intervention and control groups were evaluated using a Frailty Cox-regression model. Within the subgroup of players who had at least one hamstring injury during the soccer season, differences in days of absence of soccer between the control and intervention groups were tested using the Wilcoxon Rank test.

RESULTS

Population

A total of 80 teams were asked to participate in this RCT. Thirty- two teams, accounting for a total of 588 male soccer players, were included in the study. Sixteen teams (N = 305 players) were randomly assigned to the intervention group and 16 teams (N = 283 players) to the control group. During the study, 188 players were lost to follow-up (32%), because they did not complete the baseline questionnaire (N = 140), they did not answer the weekly questions (N = 27), they had a severe injury (N = 7), or they stopped playing soccer or transferred to another club (N = 14). Consequently, the data of 400 players were included in the final analysis, 229 in the intervention group and 171 in the control group (Figure 2 – Flowchart). Baseline characteristics are summarized in Table 2.

Exposure

During the 39-week 2016-2017 season, the total time at risk was 139 hours per player (97 hours training and 42 hours playing matches) in the intervention group and 127 hours per player (90 hours training and 37 hours playing matches) in the control group.

Hamstring injury

There were 65 hamstring injuries, of which 57 were primary hamstring injuries and 8 recurrent hamstring injuries. Thirty-one primary hamstring injuries occurred in the intervention group and 26 in the control group; 4 recurrent hamstring injuries occurred in each group (Table 3). Of the hamstring injuries, 35% were acute injuries and 54% were overuse injuries; the nature of the remaining 11% of the injuries was unknown. Hamstring muscle strains and partial ruptures were the most common types of injury and accounted for 59% of the injuries. Most hamstring injuries occurred during sprinting (39%), followed

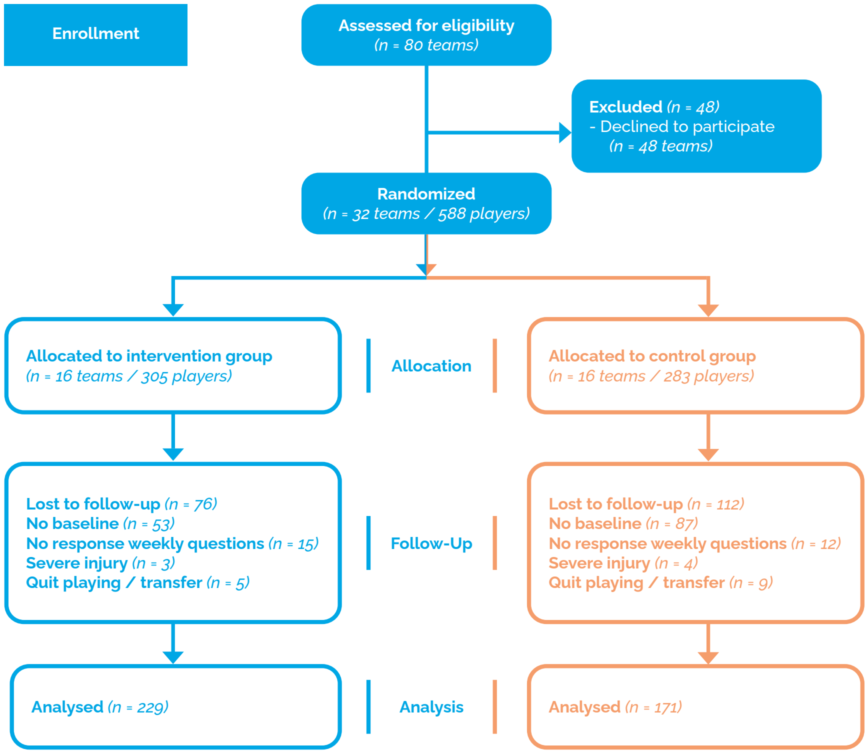


Figure 2. *Consort flow chart*

by jumping (10%) and cutting (6%). Twenty-nine hamstring injuries occurred during a match, 11 players reported the initial hamstring pain after match play, 2 occurred during the pre-match warming-up, and 15 occurred during training; the origin of 8 injuries was not known.

Incidence and severity

The number of hamstring injuries divided by the exposure time resulted in an overall injury incidence of 1.12/1000 soccer hours for the intervention group and 1.39/1000 soccer hours for the control group. Intention-to-treat analysis showed no statistically significant difference between the intervention and control groups in any hamstring injury during the season (OR = 0.89, 95% CI 0.46-1.75), and no significant difference in time-to-first hamstring injury (HR = 0.90, 95% CI = 0.48-1.70).

The mean number of days off play was 33.0 ± 42.7 in the intervention group and 21.35 ± 12.7 days in the control group. Wilcoxon Rank Testing for differences in injury severity between the intervention and control groups showed no statistically significant difference in injury severity (W = 344, *P* = 0.48).

Table 2. *Baseline characteristics*

		Intervention Group (N=229)	Control group (N=171)
Age, yrs		23.8 ± 6.4	22.2 ± 3.1
Height, cm		183.0 ± 8.6	182.6 ± 6.6
Weight, kg		78.88 ± 8.6	76.15 ± 7.4
Dutch nationality % (N)		98.3% (225)	98.2% (168)
Soccer experience, yrs		16.4 ± 4.6	16.3 ± 4.0
Leg dominance			
	Right	70% (160)	69% (118)
	Left	18% (41)	20% (34)
	Two-legged	12% (28)	11% (19)
Field position			
	Forwarder	24% (54)	21% (36)
	Midfielder	32% (74)	35% (59)
	Defender	32% (74)	36% (62)
	Goalkeeper	12% (27)	7% (12)
Hamstring injury in previous competition	(2015-2016)		
	1	15% (35)	20% (34)
	2	5% (12)	3% (5)
	3	1% (3)	4% (7)
ADL			
	Work	54% (123)	57% (98)
	Study	21% (49)	23% (39)
	Both	25% (57)	20% (34)

Compliance

Overall compliance with the BEP was 71%. Figure 3 shows the average number of BEP meters per week. Total compliance was taken as a covariate in the multilevel logistic regression analysis, which showed no evidence of a preventive effect of the BEP on the incidence and severity of hamstring injuries.

DISCUSSION

This cluster-randomized controlled trial evaluated the preventive effect of the BEP on hamstring injury incidence and severity in adult male amateur soccer players. However,

Table 3. *Comparison between intervention and control group*

		Intervention Group (N=229)	Control group (N=171)
Exposure (hours)			
	Training	97.1	90.3
	Match	42.2	36.7
	Total	139.3	127.0
Hamstring injuries (N=57)		31	26
	acute	20	15
Recurrent injuries (N=8)		4	4
Injury severity (days of soccer absence)		36 ± 67	22 ± 12
Injuries by severity (N)			
	Slight (0 days)	1	3
	Minimal (1-3 days)	3	0
	Mild (4-7 days)	6	3
	Moderate (8-28 days)	14	15
	Severe (>28 days)	7	5
Recurrent injuries (N)	Slight (0 days)	1	0
	Minimal (1-3 days)	0	0
	Mild (4-7 days)	0	0
	Moderate (8-28 days)	1	3
	Severe (>28 days)	2	1
Type of injury (N)			
	Strain	22	10
	(partial) rupture)	4	3
	Tendon injury	1	1
	Muscle cramps	4	3
	DOMS	5	9
	Overuse injury	8	9

BEP did not protect against hamstring injuries incidence or decrease hamstring injury severity.

In line with earlier studies, two out of three hamstring injuries occurred during matches and almost half of the hamstring injuries occurred during high-speed running or sprinting.[6,7,11,34,35] The most common type of injury was hamstring muscle strains. In this study, the incidence of hamstring injuries was higher than in previous studies, namely 1.3

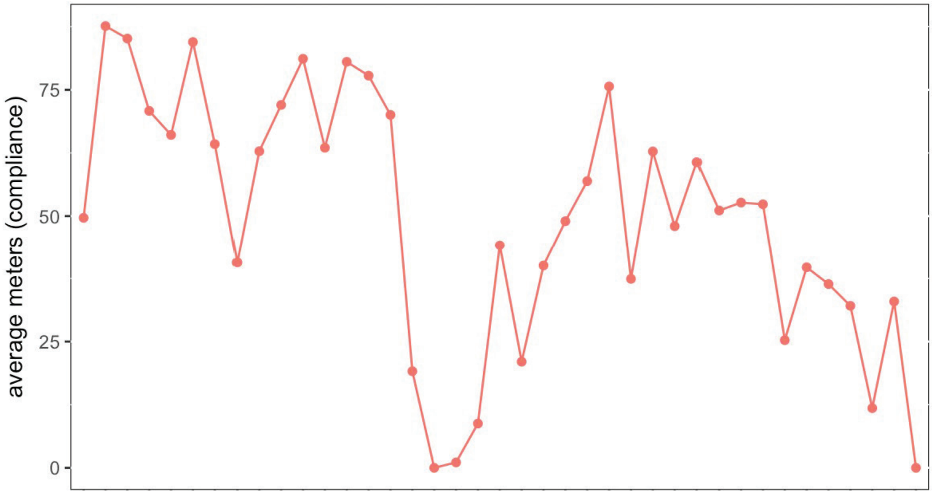


Figure 3. *Compliance during the soccer season 2016-2017*

per 1000 player hours in comparison with 0.7 per 1000 player hours,[4,12] and the severity of hamstring injuries was also different. In this study, 28% of the hamstring injuries resulted in fewer than 7 days off play compared with 17% in the NHE study; however, the incidence of severe injuries was in line with other studies.[4,12] A possible explanation for this discrepancy is a difference in the injury registration system used. In previous studies, the coaches or medical staff registered the injuries and registration forms were sent by email. In our study, we used email and SMS services and players reported hamstring injuries and exposure, with the injuries being confirmed by the medical staff. However, this approach may have led to a higher number of hamstring injuries than reported in other injury prevention studies.[36]

Despite the expected high compliance and effectiveness, the BEP did not reduce the risk or severity of injuries. Compliance is an important factor in reducing the incidence of injuries during, but more importantly after, medical trials.[37] Even though the BEP was developed to be easily incorporated into soccer training, overall compliance was 71% and lower than compliance with the NHE.[4] This might be because the BEP intervention lasted longer than the NHE intervention, 39 weeks (one whole season) compared with 12 weeks, respectively.[4] During this study, the BEP meters decreased almost linearly with time (Figure 3), which suggests that the lower compliance was in part due to the longer intervention period. A longer intervention period was chosen to prevent the detraining effects seen in previous studies, which reported a significant decrease in muscle power output and an increase in sprint time over 10 and 20 m after a 4- to 6-week detraining period.[38,39]

Another possible reason for the lack of effect of the BEP might be in the technique during the exercises. Although the BEP was designed in accordance with the prescribed training parameters of a plyometric program,[24,40] and met the specificity criteria for focusing on the late swing phase,[41] the quality of execution of the bounding exercise might influence its effect on the actual dose reaching the hamstring muscle. Unlike NHE, which is a mono-articular exercise and therefore relatively easy to perform, the bounding exercise has multiple degrees of freedom, is a dynamic exercise, and needs better neuromuscular control for good performance. The bounding exercise focuses on reaching a horizontal speed as high as possible, which is in line with an increasing load by a higher sprint speed.[8-10] If a player fails to reach a speed as high as possible, it might reduce the effect on the hamstring muscle during the late swing phase.[8,42]

A final explanation is that the Bounding Exercise Program as we developed it does not sufficiently load the hamstring or the lumbo-pelvic region sufficiently to gain a preventive effect. In the first six weeks, we included triplings, lunges, and drop lunges in order to prepare players for bounding. However, it is questionable if this already resulted in improvement of hamstring strength.[43,44] In the following six weeks, bounding was introduced. Although there is extensive evidence that plyometric training can increase eccentric strength, none of these studies specifically focus in the hamstrings. Therefore, it remains unclear if the current program does lead to the positive adaptations that we expected.

The BEP was based on recent knowledge of plyometric training[21,22,24,27,28] and implemented in a nationwide trial. Hamstring injuries were prospectively recorded via an online registration method and were confirmed by medical staff. This method was highly accessible to the participants, but the burden of weekly registration for a full season may have resulted in missing data. This problem of missing data was resolved by using sophisticated statistical analyses, and the effectiveness of BEP was analyzed with advanced innovative statistical techniques, including multilevel multiple imputation for missing data and multilevel analysis models to account for clustering effects.

Although plyometric training was expected to contribute to hamstring injury prevention (eg, increased eccentric strength, improved timing and amplitude of hamstring, gluteal, and core muscle activation, and increased passive stretch in muscle tendon complex), to date, there is no evidence that the BEP reduces hamstring injuries. This, in combination with the lower compliance with the program, raises the question whether functional and sport-specific exercises are better than less functional and complex exercises. For now, the NHE seems to be the most effective hamstring injury prevention program in male amateur soccer players. Since functional exercises are usually harder to perform and technique is important for the good-quality performance of these exercises,[45] a limitation of this large-scale intervention study is that we could not monitor how well individual players performed the BEP because of the large amount of participants. We used a top-down strategy to implement the program in the intervention group, with workshops being organized to teach staff members how to instruct, and if necessary correct, players in how to perform the BEP. All teams in the intervention group received an instruction video and hard-copy instructions. During the soccer season, the researchers visited all teams at least twice to monitor the intervention in the real-life setting. Ideally, the researchers should have visited all teams on a weekly basis to monitor performance of the BEP, but this was not logistically possible.

Future research could assess the quality of performance of the BEP and determine the load during bounding exercises. This could also provide insight into which technique results in optimal adaptation after a 12-week program. Although the BEP did not result in primary prevention, we do not know whether it reduced the rate of injury recurrence. This could be investigated by studying only those players with previous injuries.

CONCLUSION

This large cluster-randomized controlled trial found no evidence that a new functional injury prevention exercise pro- gram prevented hamstring injuries in adult male amateur soccer players.

PERSPECTIVE

Effective hamstring injury prevention programs did not accomplish an annual decrease of hamstring injuries in male amateur soccer players. One of the main reasons is long-term compliance for these programs. Besides the compliance, not only eccentric hamstring strength but also gluteal and core muscle activation patterns seem to be important factors in hamstring injury prevention. This large cluster-randomized controlled trial is the first large trial investigating the preventive effects of plyometric training on hamstring injury incidence and severity in adult male amateur soccer players. This study did not find evidence for a preventive effect of BEP in its current form. Reasons for this result can be found in a lower compliance than expected and quality of performance of the BEP. A lower compliance and poor quality of performance could both lead to undertraining which could explain the absence of preventive effect. Finally, it could also be argued that the load of the hamstring or lumbo-pelvic region was insufficient to gain protective adaptations, regardless of the quantity and quality of BEP.

ETHICAL APPROVAL AND PATIENT CONSENT

This study is approved by the Medical Ethics Committee of the University Medical Center Utrecht (16-332\C). All participants included in this study have provided written in- formed consent.

ACKNOWLEDGEMENTS

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6

7

Players' age, experience and perceptions affect adherence to an injury prevention program in male amateur football

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ABSTRACT

Adherence to injury prevention programs in football often remains low and this is thought to drastically reduce the effects of injury prevention programs. Coaches, medical staff and players are stakeholders in injury prevention. While the reasons why stakeholders implement injury prevention programs have been investigated, player characteristics (i.e. age and educational level) and player's perceptions about these programs might influence their adherence to them. Therefore, the purpose of this study was to investigate the relationships between player characteristics and adherence, and between player perceptions and adherence following a recently implemented injury prevention program. Data from 98 of 221 players from the intervention group of a large cluster-RCT were analyzed. Player characteristics were recorded at baseline, hamstring injuries and compliance were registered prospectively and player perceptions about the injury prevention program were obtained after the football season. Adherence was better among older and more experienced football players, and players who considered the prevention program as more useful, less intense, more functional and less time-consuming. Previous hamstring injuries, hamstring injuries during the football season, educational level, difficulty of the program and intention to continue the exercises were not significantly associated with adherence. When implementing an injury prevention program these player characteristics and perceptions could be taken into account.

Keywords: Compliance, Injury prevention, adherence, soccer

INTRODUCTION:

Effectiveness of injury prevention exercise programs (IPEP) depends on both the effectiveness of the program itself and on players' adherence to the program[1,2]. For hamstring injuries, this can be illustrated with the Nordic Hamstring Exercise (NHE). Even though the NHE reduces hamstring injury occurrence by approximately 70% when adherence is high[3–5], athletes do not comply sufficiently. This poor adherence reduces the preventive effect drastically[6,7]. Reasons for low adherence are lack of knowledge about the program, no motivation and no consensus for IPEPs within staff[7].

To increase motivation and thereby adherence of both staff and football players, a new hamstring IPEP was developed: the bounding exercise program (BEP)[8]. This program consisted of plyometric exercises that can be easily integrated into the warming-up and are known to enhance football-specific performance[9]. A cluster-RCT studying the effectiveness of the BEP revealed that adherence decreased during the football season and an absence of evidence for a preventive effect[10].

In team sports like football, coaches, medical staff and players are stakeholders in implementing IPEPs[11]. Previous studies have focused on the beliefs of coaches as the deliverers of IPEPs in a variety of sports, but little is known about the motivators and barriers to performing IPEPs of male amateur football players[11,12].

Lessons could be learned from other domains such as patient compliance with medication intake. These studies have reported associations with personal characteristics, therapeutic factors, socio-economic factors, disease related factors and health care system factors [13]. Furthermore, the Health Beliefs Model (HBM) describes six constructs that influence health related behavior which is directly related to adherence: (1)perceived susceptibility, (2)perceived seriousness, (3)perceived benefits, (4)perceived barriers, (5) cues to action, and (6)self-efficacy[12,14–16]. These constructs might explain why players' perceptions of IPEPs change when they have insight into their own individual risk[17].

Previous information indicated that personal characteristics (i.e., age, education level), players perceptions about their injury risk and players' perceptions about the preventive measure are important for good adherence to IPEPs, but further knowledge about these relationships is needed[11,12]. Therefore, the aims of this study were to determine the relationship between player characteristics and adherence, and the relationship between player perceptions of the BEP and the adherence to the program.

MATERIALS AND METHODS

This study was part of a large nationwide cluster-RCT investigating the effectiveness of BEP[8,10] in 400 male amateur football players. The medical ethics committee of the University Medical Center Utrecht approved this trial (16-332/C) and it was registered in the Dutch trial registry (NTR6129). The study protocol has been described extensively elsewhere[8].

Participants

Adult male football players competing in the Dutch first class amateur competition and allocated to the intervention group of the cluster-RCT and who both filled in the baseline and evaluation questionnaires, were included in this analysis. Players had an average age of 23.8 ± 6.4 and had 16.4 ± 4.6 years of football experience and completed two training sessions per week on average [18].

Procedures and data collection

All players gave written informed consent prior the study. The BEP was introduced to the coaches and medical staff in workshops and the researchers visited the clubs at least twice during the football season. They were available for questions at any time. Coaches and medical staff were instructed to implement the BEP at the end of the warm-up in the training sessions (twice per week). The BEP consists of a build-up and maintenance program. During the built-up the BEP was executed over 20 or 30m, during the maintenance program the BEP was performed over a 30m distance[8].

Players completed a baseline questionnaire consisting of personal characteristics such as age, work/education level, years of football experience and number of previous hamstring injuries during the last football season. During the subsequent football season, the players weekly registered whether they had a hamstring injury and over how many meters they performed the BEP. Players were instructed to register how many meters they performed BEP even if they were injured. In the weeks injured players could not attend training sessions, they were instructed to register that they performed 0 meters of BEP. Adherence was calculated as the number of meters BEP performed expressed as a percentage of the meters of BEP prescribed. Hamstring injuries were self-reported by the players and validated by the medical staff. Both the injured player and the medical staff filled in a hamstring injury questionnaire about the injury. At the end of the study, players completed the evaluation questionnaire about their perceptions of the BEP. This questionnaire consisted of questions scored on a scale from 1-5 about the usefulness of the program, its intensity, difficulty and functionality, the time it took to perform and the intention to perform the program in the coming season.

Statistical analysis

SPSS-25 was used for the analysis[19]. Players who filled in the baseline and evaluation questionnaires were included in the analysis. Weekly registrations that were not filled in and injury periods were assumed to be non-adherent. For the first aim, Pearson's product-moment correlations were calculated between adherence and age and years of football experience. Analyses of variance (F-tests) were executed to calculate the differences in average adherence between players with and without previous hamstring injuries and high or low education level. For the second aim, analyses of variance (F-tests) were executed to calculate the differences in perception about the BEP in relation to adherence.

RESULTS

Data of 98 male amateur football players were included in the analysis. Players were 24.6±4.0 years old on average, had 18.5±4.6 years of football experience, 15 players had one previous hamstring injury and 5 players had two previous hamstring injuries. During the subsequent season 12 players sustained a hamstring injury.

Player characteristics and adherence

Significant but low correlations were found between adherence and age (r =0.25, 95% CI 0.054-0.429), and between adherence and years of football experience (r=0.20, 95% CI 0.004-0.387). Adherence did not significantly differ per season between players with no previous hamstring injuries and players with one or two previous hamstring injuries ($F_{1,96}$=0.874,p=0.420), between players with or without new hamstring injuries ($F_{1,97}$=0.228,p=0.634) or between high or low educational level ($F_{1,97}$=0.602,p=0.512)(Figure 1).

Player's perceptions towards BEP and adherence

Players who perceived BEP as useful (personal motivation) in hamstring injury prevention were significantly more adhered than players who did not believe BEP was useful ($F_{1,97}$=2.747,p=0.033). Players perceiving BEP as less intense ($F_{1,97}$=3.202,p=0.027), as more functional ($F_{1,97}$=4.181,p=0.018) and as less time-consuming ($F_{1,97}$=4.317,p=0.003) showed higher adherence than the group reporting the contrary.

No evidence was found for a relationship between difficulty of the program and adherence of players ($F_{1,97}$=0.637,p=0.593), and between adherence during the study and intention of performing the BEP in the coming season ($F_{1,97}$=1.465,p=0.219)(Figure 2).

Player perceptions about BEP and adherence

Players who perceived BEP as useful (personal motivation) for hamstring injury prevention were significantly more adherent than players who did not believe BEP was useful

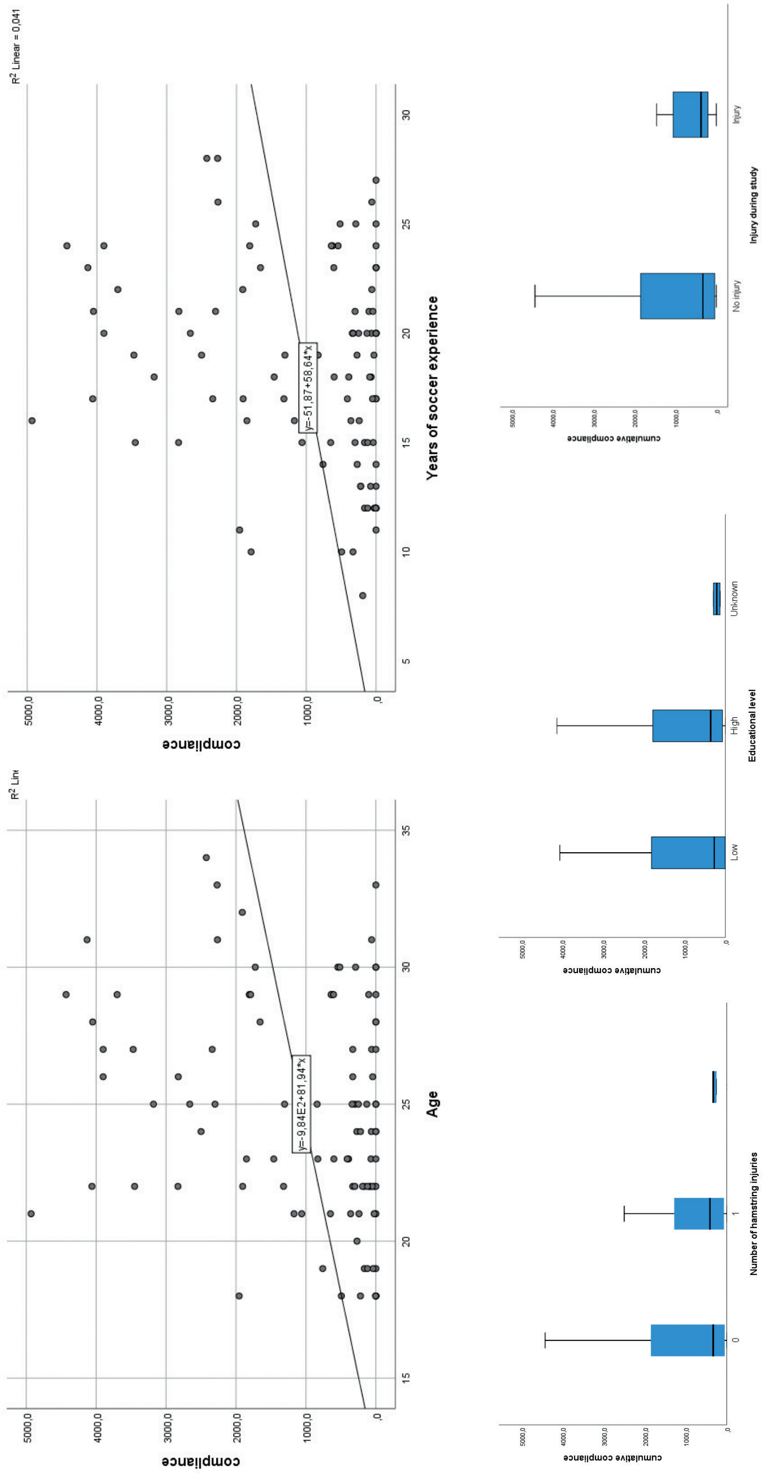

Figure 1. *Relationship between player characteristics and adherence.*

($F_{1,97}$=2.747,p=0.033). Adherence was higher in players who perceived BEP as less intense ($F_{1,97}$=3.202,p=0.027), as more functional ($F_{1,97}$=4.181,p=0.018) and as less time-consuming ($F_{1,97}$=4.317,p=0.003) than the group that reported the contrary.

No evidence was found for a relationship between difficulty of the program and adherence of players ($F_{1,97}$=0.637,p=0.593). Additionally, there was no evidence of a relationship between adherence during the study and intention of performing the BEP in the coming season ($F_{1,97}$=1.465,p=0.219)(Figure 2).

DISCUSSION

The main findings in this study were that increased age and years of football experience were poorly related to higher adherence and players who considered BEP as useful, less intense, functional or less time-consuming had higher adherence than players who reported otherwise. Furthermore, no significant associations were found between adherence and educational level, previous and new hamstring injuries, difficulty of the program or intentions for the next season.

Player characteristics and adherence to IPEPs

Older and more experienced players tended to adhere better to IPEPs than the younger and less experienced players. These older players seem to have developed a certain routine and were more motivated to expend effort in staying fit than younger players. Older, experienced players previously reported to have learned how to apply and integrate preventive measures and become more accountable for their own health protection[11].

7

No significant relationship was found between previous or new hamstring injuries and program adherence to the hamstring injury prevention program. This was unexpected since players tend to change their individual risk-taking behaviour when an event (i.e., hamstring injury) occurs [17]. Players that sustained an injury during the football season while using a hamstring IPEP might have thought (developed the idea) that the program failed to prevent the injury. This could also be seen as cue to change their behavior and not adhere to the IPEP[14].

Player perceptions and adherence to IPEPs

Players who perceived the BEP as useful in hamstring injury prevention adhered better to the program. This is in line with the thought that personal motivation for IPEPs depends on perceived benefits, perceived severity of the injury and influences the intention to continue using an IPEP [14]. Perceptions and knowledge about the effectiveness of the IPEP are key to successful implementation[7,12]. Perceptions about intensity, functionality,

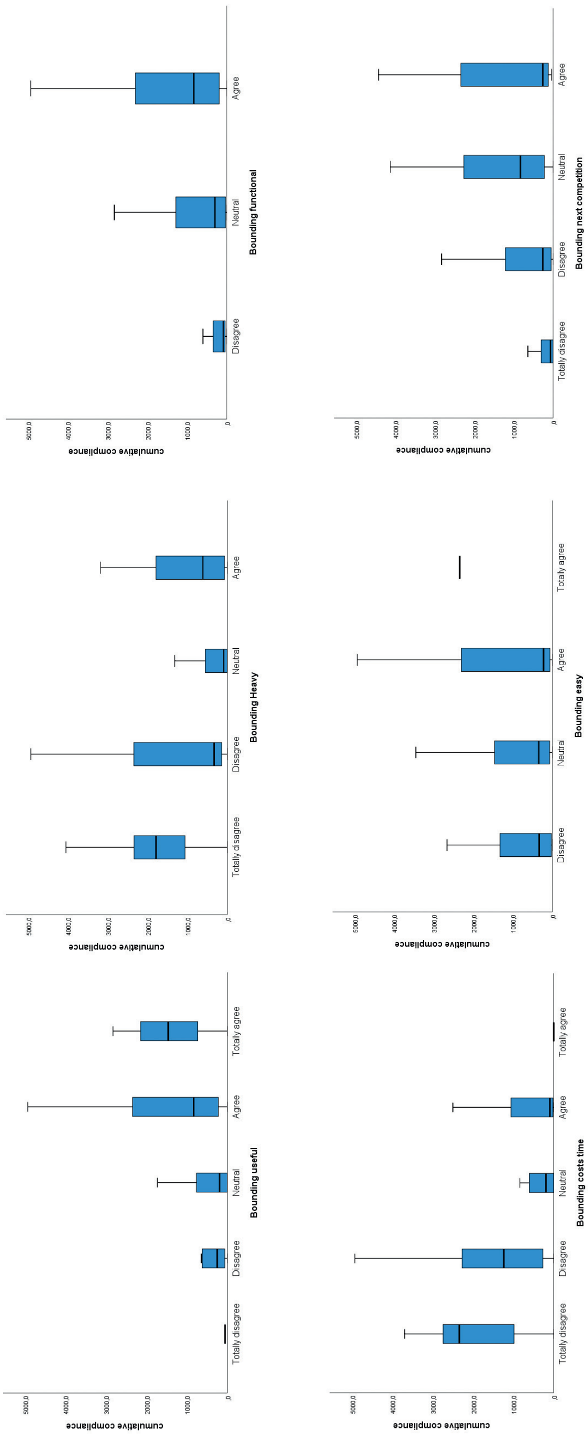

Figure 2. *Differences between players' perception of the BEP in relation with adherence*

and time expenditure are also related to adherence and should be considered when designing and implementing an IPEP in football.

Strengths and limitations

This study provides an insight into arguments for performing IPEPs and gives direction in what needs to be considered when designing an IPEP.

Although data were collected in a large cluster-RCT, power was low for correlations including previous and new hamstring injuries, due to the relatively low hamstring injury incidence.

Furthermore, adherence was probably underestimated because players with missing weekly reports were considered non-adherent. This decision was made because even when players could not attend training sessions, they had to register that they performed 0 meters of BEP. Nevertheless, this has likely created some measurement error which may have affected the correlation coefficient[20]. Additionally, only players that filled in both questionnaires were included, and therefore selection bias cannot be ruled out.

This study focused on adult male football players as the key stakeholders. In injury prevention, coaches and medical staff members are stakeholders as well[11]. These members, including the group dynamics, were not included in this study.

Recommendations for implementation of preventive measures and future research

To design and implement an IPEP successfully, the main focus should lie in explaining its effectiveness to players. Older and more experienced players can be considered as early adopters, since they seem more motivated to adopt for IPEPs. For younger players, feedback about their injury risk could be provided because they seem less accurate in estimating their injury risk[21]. Future research could focus on methods to encourage male amateur football players to change their sports behaviour. Theories from the field of social psychology, as 'social proof', focus on group dynamics[22].

Besides group dynamics within the team, dynamics between coach, medical staff and players seem important as well[11]. Football is a team sport and warm-ups including general injury prevention programs are usually supervised by the coach, medical staff or team captain. This study showed differences in adherence within one team, which might indicate that players can choose to participate in injury preventive measures. Future research could look into these group dynamics.

This study suggests that IPEPs that consist of functional, not too intense exercises that are not time-consuming contribute to better adherence. Even though the BEP aimed to comply to these perceptions, adherence decreased during the RCT. This raises the question whether we need to stick to IPEPs incorporated in group warm-ups or whether we need new thoughts and focus on implementing football-specific preventive exercises or individual targeted preventive measures.

CONCLUSIONS

Effectiveness of IPEPs in football depends on their preventive effect and player adherence with the program. Age, years of experience and player perceptions of program usefulness, functionality, intensity and time investment correlate with adherence. Previous and new hamstring injuries, educational level, difficulty of the program and intention to continue were not related to adherence.

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DISCLOSURE STATEMENT

The authors report no conflicts of interest relevant to this article

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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 (RTP) in sports 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 because of 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[22,23], 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.

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 Electronic Supplementary Material Appendix S1). 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 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 farfetched.

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 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 1).

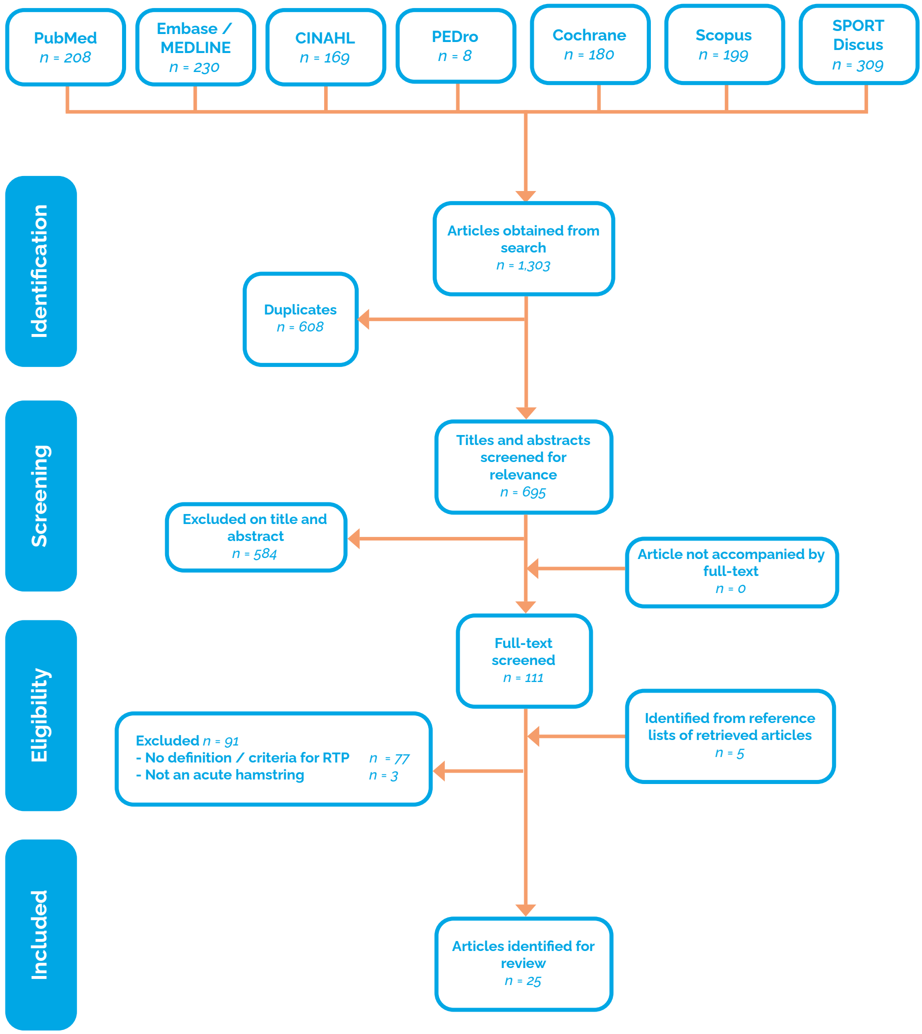

Figure 1. *Study selection flow chart*

DEFINITION OF RTP

Thirteen articles (52%) defined RTP (Table 1).

Coding

Open coding of the relevant content of the articles resulted in open codes for "definition of RTP after hamstring injury" (Table 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 2).

Table 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]	Prospec-tive 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

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Table 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]	Prospec-tive 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 commen-tary	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 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

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Table 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]	Prospec-tive 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 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 commen-tary	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]	Retro-spective 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.

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***Table 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]	Retro-spective 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.
Malliaropou-los 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
Mendigu-chia and Brughelli[16b]	Clinical commen-tary	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)

Table 1. *Continued.*

Reference	Study design	Study population, sex, age in years (mean, SD)	Definition of hamstring injury	Definition of RTP after hamstring injury[a]	Criteria for RTP after hamstring injury[a]
Moen et al.[49]	Prospec-tive 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 commen-tary	N/A	Not provided	Not provided	Normal strength (>90% of the unaffected side) Normal range of motion Performance at training dictates readiness for matches.
Petersen and Hölmich[52]	Clinical commen-tary	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

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Table 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 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
Sanfilippo et al.[54]	Prospec-tive 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

Table 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]
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.[25b]	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]	Prospec-tive 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 (eg, 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.

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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].

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" were used as terms to define RTP[26,55,56]. Most articles provided additional medical criteria to support the RTP definition[26,38,41,48,55,56].

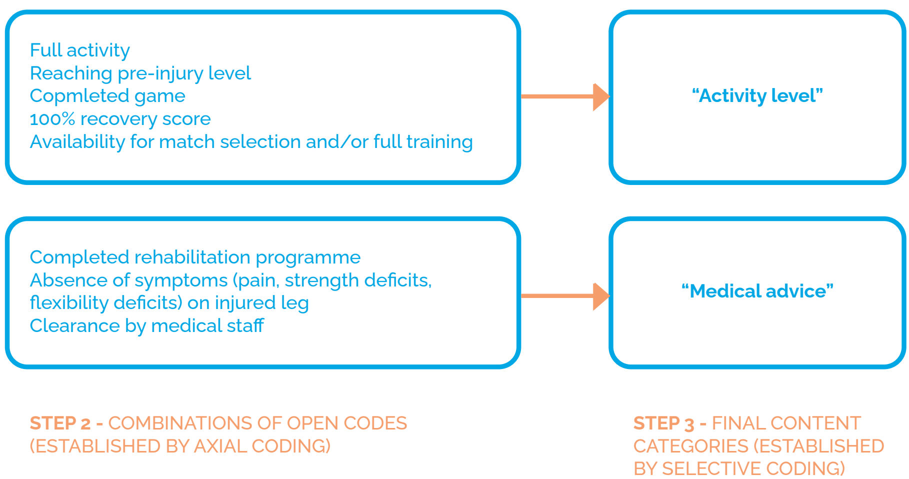

Figure 2. *Axial and selective coding of definition for RTP - step 2 and 3 of content analysis*

RTP CRITERIA

Of the 25 included articles, 23 articles (92%) provided criteria for RTP after a hamstring injury (Table 1).

Coding

After open coding and subsequent axial coding of criteria for RTP (Table 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 3).

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[25,26,33,36,38,40,41,42,43,45,47,50,52,54,55,56]. In some studies, pain was tested via direct palpation of the hamstring muscle[36,37,54,55]. Askling et al. and A 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 criterion 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[16,26,36,38,40,41,42,43,45,46,47,48,50,51,54,55]. 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°, 180°, 240°, and 300° per second[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 7 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.

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Functional Performance

Thirteen studies reported performance during field testing as a criterion for RTP after hamstring injury[25,26,37,42,43,45,46,47,48,50,51,53,56]. 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[26,41,56], but none of the studies described the content of such a program.

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 EMG 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

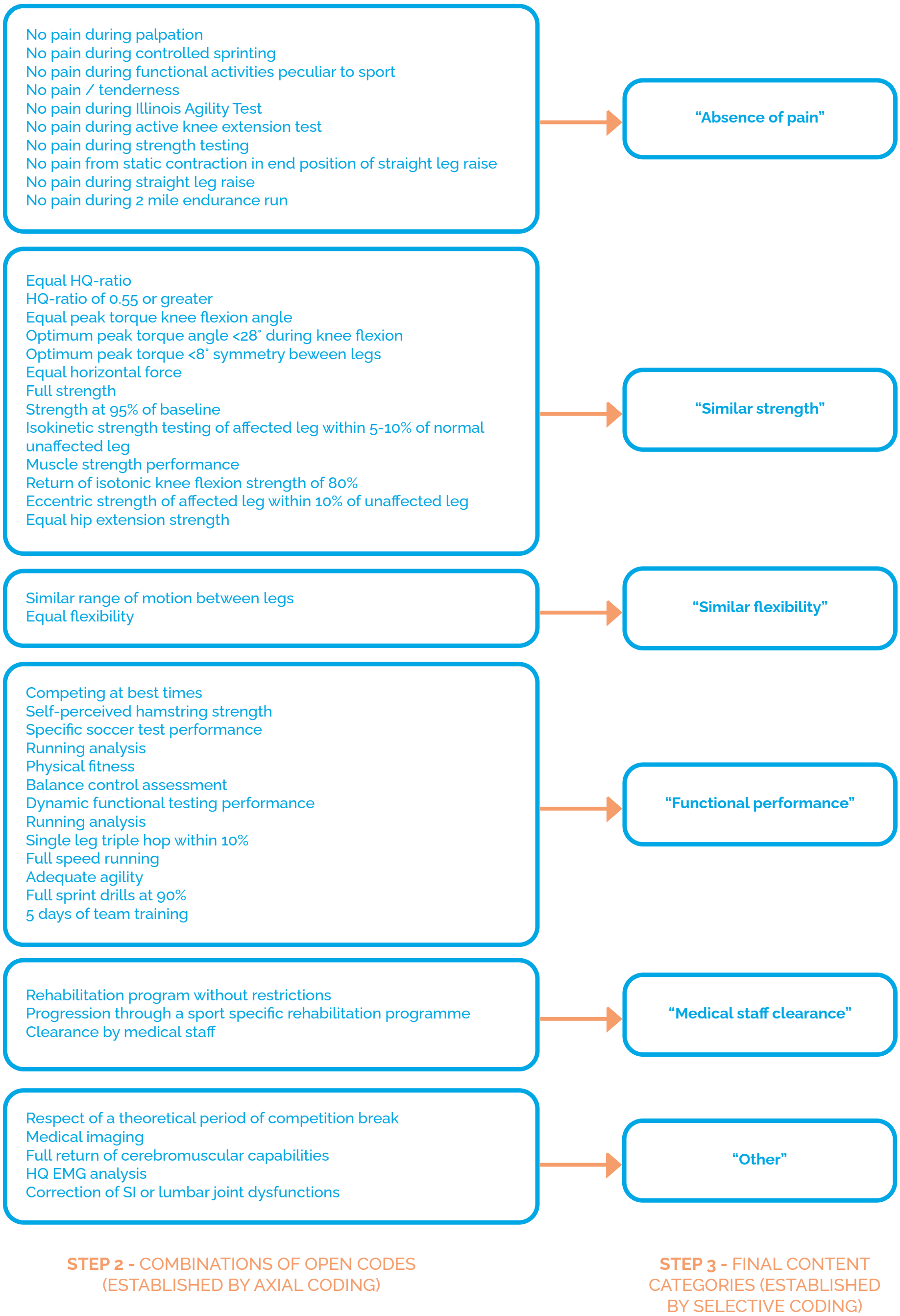

Figure 3. *Axial and selective coding of criteria for RTP - step 2 and 3 of content analysis*

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 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 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 3 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 is 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].

So far, none of the RTP-criteria have been validated with regards to the RTP-decision after hamstring injury. Only 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 <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 due 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[25,26,37,42,43,45,46,47,48,50,51,53,56]. 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', need 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 A 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 in order to facilitate hamstring injury management and reduce hamstring injury recurrence.

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Conflicts of Interest

Nick van der Horst, Sander van de Hoef, Gustaaf Reurink, Bionka Huisstede and Frank Backx declare that they have no conflicts of interest relevant to the content of this review.

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The prognostic value of the hamstring outcome score to predict the risk of hamstring injuries

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Resubmitted

ABSTRACT

Objectives: Hamstring injuries are common among soccer players. The hamstring outcome score (HaOS) might be useful to identify amateur players at risk of hamstring injury. Therefore the aims of this study were: To determine the association between the HaOS and prior and new hamstring injuries in amateur soccer players, and to determine the prognostic value of the HaOS for identifying players with or without previous hamstring injuries at risk of future injury.

Design: Cohort study

Methods: HaOS scores and information about previous injuries were collected at baseline and new injuries were prospectively registered during a cluster-randomized controlled trial involving 400 amateur soccer players. Analysis of variance and t-tests were used to determine the association between the HaOS and previous and new hamstring injury, respectively. Logistic regression analysis indicated the prognostic value of the HaOS for predicting new hamstring injuries.

Results: Analysis of data of 356 players indicated that lower HaOS scores were associated with more previous hamstring injuries ($F=17,4$; $p=0,000$) and that players with lower HaOS scores sustained more new hamstring injuries ($T=3.59$, $df=67.23$, $p=0.001$). With a conventional HaOS score cut-off of 80%, logistic regression models yielded a probability of hamstring injuries of 11%, 18%, and 28% for players with 0,1, or 2 hamstring injuries in the previous season, respectively.

Conclusion: The HaOS is associated with previous and future hamstring injury and might be a useful tool to provide players with insight into their risk of sustaining a new hamstring injury risk when used in combination with previous injuries.

Keywords: Hamstring injury, soccer, football, prevention, prognostic value, injury risk.

INTRODUCTION

Hamstring injuries are the most common muscle injuries in soccer [1] and can be responsible for a long absence from playing and have a high recurrence rate [1,2]. Recurrent hamstring injuries result in a longer absence from playing and require more extensive and longer rehabilitation [3]. Even though the FIFA11+ and the Nordic Hamstring Exercise (NHE) programmes are effective for primary injury prevention [4,5], the incidence of hamstring injuries continues to increase annually [6].

One explanation for this annual increase is poor long-term compliance with prevention programmes [7,8]. This is often seen after a study is concluded, when research staff stop supervising the intervention. As a result, prevention programmes are less effective in practice than in a study setting [9]. A reason for poor compliance might be that primary preventive measures target all players, and not specifically those at high risk of injury. At this point all players need to perform the same preventive exercises, no matter the risk of injury[10].

Research has shown that athletes are more willingly to participate if they have been injured in the past and have a higher risk of recurrent injury [11]. This willingness was recently confirmed in amateur soccer players [7]. This suggests that players who have been injured in the past change their individual risk-taking behaviour and are more compliant with preventive measures.

Knowledge of risk factors for injury is needed in order to provide players with insight into their individual risk of hamstring injury[12,13]. Several potential intrinsic (i.e. age, weight, ethnicity, previous injury, strength and flexibility) and extrinsic (i.e. playing position, field condition, weather) risk factors have been investigated [14–17], but only age and previous hamstring injury have been consistently associated with the risk of hamstring injury[14,15,18]. That previous hamstring injury is a consistent risk factor, implies primary hamstring injuries need to be prevented in order to prevent the injury-reinjury cycle.

Injury prevention programmes are typically performed groupwise by all team members [10], but targeting only those players with a high hamstring injury risk could contribute to a more successful implementation of prevention programs. This necessitates assessment of a player's injury history, bearing in mind that not all players with a previous hamstring injury sustain a new hamstring injury, and not having a history of hamstring injury is no guarantee that those players will not sustain a primary hamstring injury [10].

While there are no markers to detect early stages of hamstring injuries [10], pain and soreness during and after (sport-specific) exercises, pain and soreness during daily activities, and fear of (re-) injury are associated with musculoskeletal injuries [16,19]. The

Hamstring Outcome Score (HaOS) might be useful for identifying players with these symptoms.

The HaOS has been used in research to evaluate complaints after rehabilitation and to classify soccer players as being at low or high risk of hamstring injury [20,21], but it has not been studied in daily soccer practice. The HaOS was developed following the same principles as the extensively used and validated Hip And Groin Outcome Score (HAGOS), Foot and Ankle Outcome Scores (FAOS) and the Knee Osteoarthritis Outcome Score (KOOS) and assesses five domains: soreness, symptoms, pain, activities (sports), and quality of life[22,23]. The first four domains are relevant to daily life and to soccer and sport-specific tasks, while the domain quality of life measures fear of re-injury.

Players are conventionally classified as being at high risk of hamstring injury with a history of hamstring injury or a HaOS score of <80% and at low risk with a score >80% [20]. However, the probability of injury with a HaOS score of 80% and whether the score is associated with number of injuries in the past remain unclear. Therefore, the aims of this study were (1) to determine the association between the HaOS score and previous hamstring injury, (2) to determine the association between the HaOS score and new hamstring injuries, and (3) to determine whether the HaOS score, with or without previous hamstring injury, is a valuable prognostic factor in hamstring injuries in soccer players.

METHODS

Data were collected in 2016–2017 in large cluster-randomized controlled trial (cluster RCT) investigating the preventive effect of a Bounding Exercise Program on hamstring injuries in adult male amateur soccer players [24]. This study was approved by the Medical Ethics Committee of the University Medical Center Utrecht (16-332\C) and was registered in the Dutch Trial Registry (NTR6129).

Adult male amateur soccer players aged 18-45 years who played in the first-class amateur soccer league in the Netherlands were eligible for participation. Players with insufficient understanding of the Dutch language were excluded. All players eligible for inclusion received an information letter before the start of the cluster-RCT and signed an informed consent.

In this cluster RCT, 400 soccer players from 32 amateur soccer teams were prospectively followed up during an entire soccer season (2016-2017). Each player filled in a baseline questionnaire that included HaOS score and various player and demographic characteristics such as age, weight, height, years of soccer experience, and previous (hamstring) injuries. Self-reported information about (hamstring) injuries and match- and training exposure were collected weekly. If an injury was reported, the player sought medical attention and the characteristics of the injury were registered using questionnaires completed by the medical staff and player [24].

The original HaOS consist of two parts. Part 1 consists of hamstring injury history. Part 2 was translated in Dutch [21] and is in line with the validated Dutch HAGOS and FAOS and consists of five dimensions: (1) Symptoms, (2) Soreness, (3) Pain, (4) Function, Activities of Daily Living and Sport, and (5) Quality of Life[22,23]. The questions were scored 0 to 4, from no complaints to maximum complaints[20]. The HaOS score can be calculated as an overall score and a score for each dimension. Scores were calculated as percentages of the maximum score, with a player with no complaints scoring 100%. Scores were calculated by 1-(score/ maximum score) * 100%. A score of 80% or more was considered to indicate a low risk of hamstring injury and a score of less than 80% as being indicative of a high risk of hamstring injury [20].

The association between the baseline HaOS score and hamstring injuries was studied in three separate analyses. First, we studied the association between the mean HaOS score and the number of injuries (categorized as: 0, 1, 2, 3 or more) in the season preceding baseline. Differences in means for each of the HaOS subdomains (Symptoms, Soreness, Pain, Activity, Quality of Life) and the total HaOS scale were tested with F-tests in separate ANOVAs. Second, we compared the mean HaOS subdomain and total scores between players with and without (any number) hamstring injuries in the current soccer season. Confidence intervals for the differences in means were calculated. Lastly, in our main analysis we studied the baseline HaOS total score as a prognostic factor to predict occurrence of hamstring injury during the current season. We first fitted a univariable logistic regression model with hamstring injury as the outcome and baseline HaOS total score as the predictor. A second model was fitted that allowed the HaOS predictor effect to be non-linear via a restricted cubic spline (4 knots). A third bivariable logistic model was fitted with both HaOS total score and hamstring injuries in the previous season as the predictor. Our final fourth model allowed for interaction between the HaOS score and previous injuries. For the main analysis, data were missing for 44 HaOS total scores and were multiple imputed on the assumption that the data were missing at random [25] using aregImpute (rms R-package), which allows for non-linear effects of the imputation predictors via restricted cubic splines [26]. All data were analysed with the statistical language and software program R, version [27].

RESULTS

All 400 players filled in the baseline questionnaire and responded to weekly questions regarding their soccer exposure and injuries. Of these players, 356 players (89%) completed all the questions of the baseline HaOS. At baseline, 103 players reported having sustained a hamstring injury in the previous season (2015-2016). During the season

2016-2017, 57 of the 356 players sustained a hamstring injury verified by the medical staff and 24 of those 57 players had a hamstring injury in the previous season (2015-2016). The players in the injury and no-injury groups did not differ in age (25.74 (4.20) / 24.58 (6.03)), height 183.60 (5.70) / 184.06 (6.47)), weight (78.99 (6.71) / 78.73 (8.08)) and years of soccer experience (19.20 (4.57) / 18.59 (4.63)), respectively. The players with and without a previous hamstring injury also did not differ on those characteristics (age 24.97 (4.24) / 24.86 (4.74); length 183.24 (6.60) / 184.45 (6.11); weight 78.85 (7.74) / 78.92 (7.95); years of experience 19.31 (4.29) / 18.56 (4.69).

The first analysis indicated the association between the baseline HaOS and previous hamstring injuries. A higher number of previous hamstring injuries was associated with a lower HaOS total score and lower HaOS subdomain scores at baseline (Figure 1). Between group analysis revealed significant differences between the injury and no-injury groups in mean total HaOS score (F (3,351) = 17.44, p=0,000) and in mean HaOS subdomain scores (symptoms: F(3,373) = 13.171, *p*=0,000; soreness: F(3,368) = 6.999, *p*=0,000; pain: F(3,367) = 10.458, *p*=0,000; activity: F(3,368) = 8.209, *p*=0,000 and quality of life: F(3,368) = 24.243, *p*=0,000). The HaOS total score ranged from 29.69% to 100%.

Secondly, differences in HaOS scores at baseline between players who did or did not sustain a new hamstring injury in the subsequent season are presented in table 2. Again, there were significant differences in mean total HaOS score and mean subdomain scores between players in the injury and no-injury groups. Players with a new hamstring injury in the current season had significantly lower HaOS domain scores at baseline than did players who did not sustain a new hamstring injury in the current season (table 1).

Table 1. *HaOS scores (mean± SD) of soccer players who did or did not sustain an injury in the current soccer season.*

	INJURY (N=57)	NO INJURY (N=299)	MEAN DIFFERENCE	CONFIDENCE INTERVALS	P-VALUES
SYMPTOMS	65.45 (22.94)	78.22 (21.04)	12.77	6.65 – 18.89	0.000
SORENESS	75.64 (16.56)	84.46 (16.45)	8.83	4.06 – 13.59	0.000
PAIN	80.00 (18.01)	87.24 (14.35)	7.24	2.13 – 12.35	0.006
ACTIVITY	85.45 (17.37)	91.28 (16.04)	5.82	0.82 – 10.82	0.023
QUALITY OF LIFE	78.41 (23.90)	87.50 (16.85)	9.09	2.38 – 15.80	0.009
TOTAL HAOS	77.07 (16.31)	85.53 (13.78)	8.46	3.75- 13.16	0.001

Thirdly, previous hamstring injury and the HaOS score as a prognostic factor was investigated. The performance of the logistic regression models that allowed the HaOS predictor effect to be non-linear via a restricted cubic spline and the model that allowed for an interaction between the HaOS was not materially different. We will therefore focus on the two simpler models.

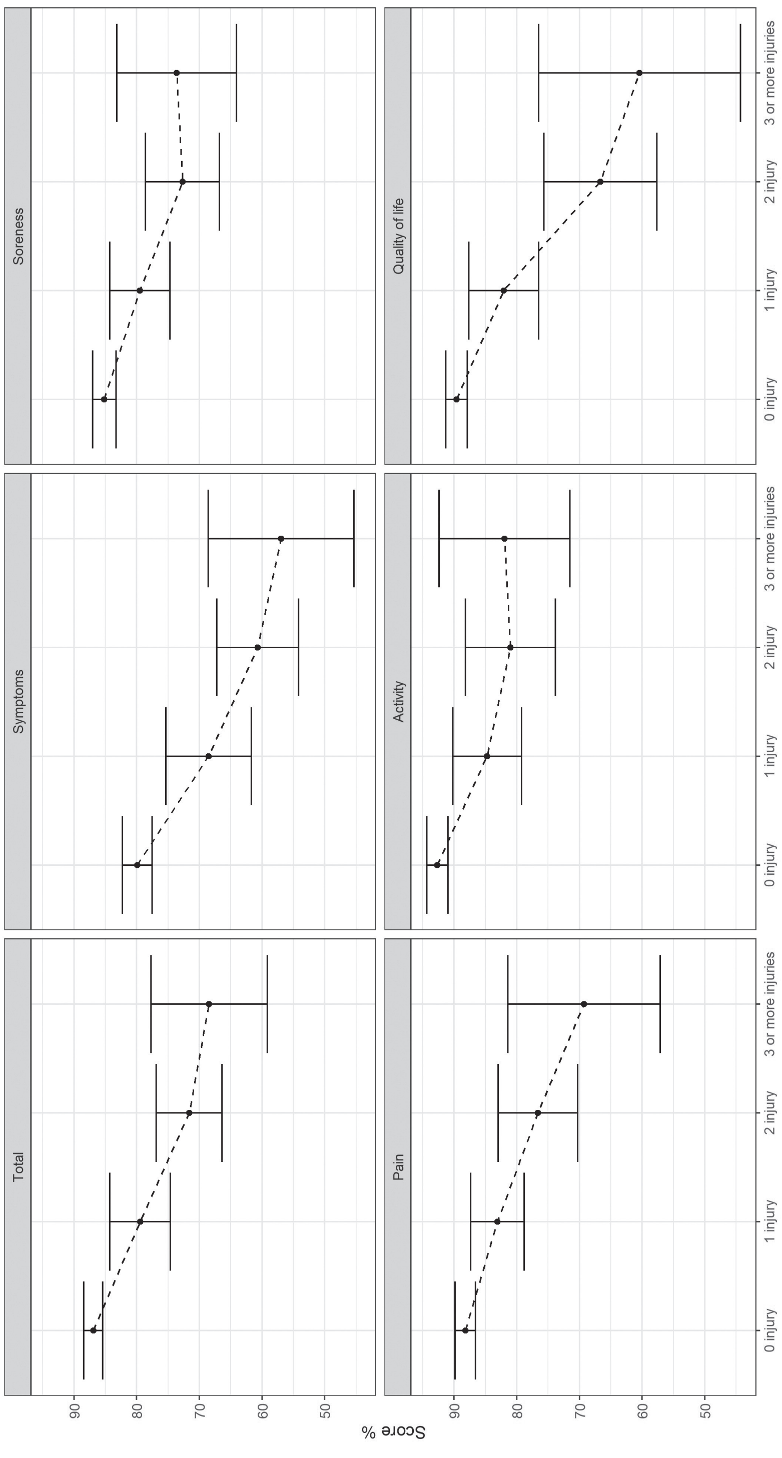

***Figure 1.** Association between previous hamstring injuries and HaOS*

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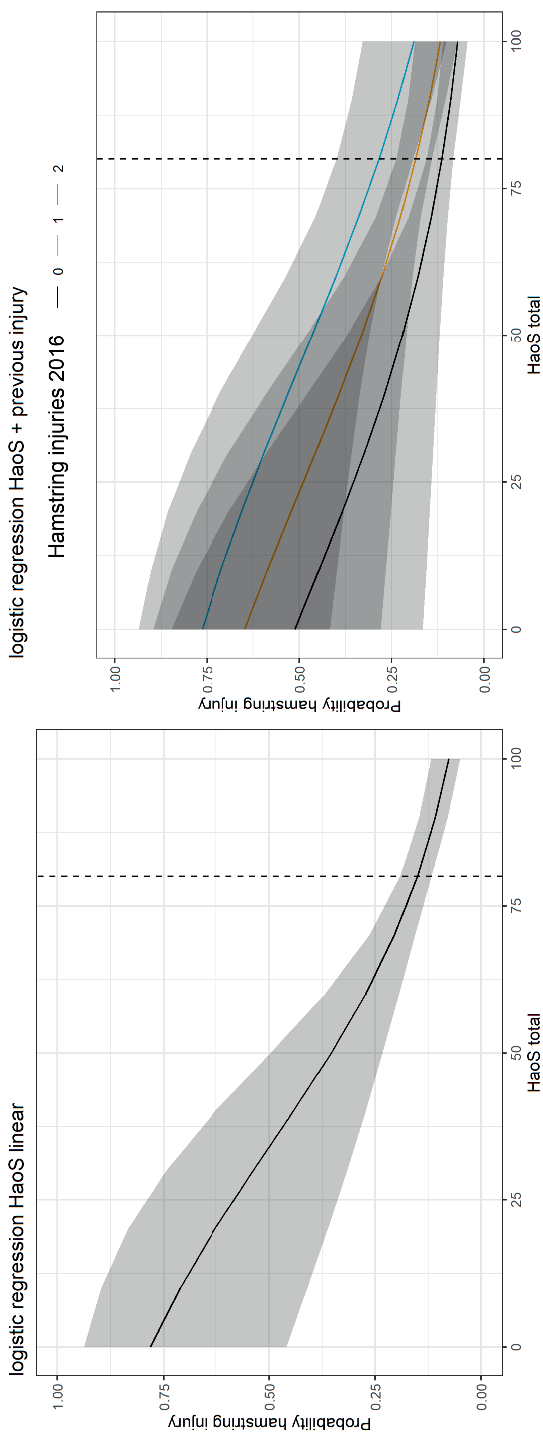

Figure 2. *Hamstring injury prediction plots based on logistic regression analysis*

Univariable logistic regression analysis with baseline HaOS score as the only predictor of hamstring injury in the current season resulted in a model (after imputation and pooling) with an area under the ROC curve of 0.672 and a Nagelkerke R^2 index of 0.075 (intercept: 1.27 (0.73), regression coefficient:-0.04 (0.01)). Adding the number of injuries sustained in the previous season as a predictor increased the fit of the model (Likelihood ratio test, Chi-square = 13.38, df = 1, p < .001). This bivariable logistic regression model had an area under the ROC curve of 0.690 and a Nagelkerke R^2 index of 0.131 (intercept: 0.04 (std err: 0.844), HaOS score coefficient:-0.03 (std err: 0.01) and sustained hamstring injuries: 0.56 (std err: 0.16)).

Figure 2 visualizes the predicted risk (i.e. estimated probability of a player suffering a hamstring injury in the current season) as a function of the HaOS score only (left panel) and with number of sustained hamstring injuries in previous season added (right panel). For reference, we added a reference line that marks the cut-off (80%) below which players are traditionally classified as being at "high risk" of sustaining hamstring injury [20]. With this cut-off, the hamstring injury risk was approximately 11%, whereas players with one or two hamstring injuries in the previous season had a risk of 18% and 28%, respectively.

DISCUSSION

This study investigated the value of the Hamstring Outcome Score (HaOS) measured at the start of the soccer season as a prognostic factor to predict hamstring injury in that season. Players who had sustained an injury in the previous season had lower HaOS total and subdomain scores than did players without a previous hamstring injury. Further, players who sustained a new hamstring injury had lower HaOS total and subdomain scores than did players who did not sustain a hamstring injury in the current season. The ability of the HaOS score to predict new hamstring injury changed depending on the number of hamstring injuries sustained in the previous season. The probability of a new hamstring injury increased from 11% with no previous hamstring injury, to 18% with one previous hamstring injury and 28% with two previous hamstring injuries.

As expected, players who had sustained hamstring injuries in the previous season had lower total HaOS score and subdomain scores, indicating that they experienced more severe symptoms, more soreness and pain, less function in sports, and lower quality of life [14,15]. An explanation for the high recurrence rate of hamstring injuries is a too early return to play [28]. Our data show that players with previous hamstring injuries that occurred between 2 and 12 months ago still had lower HaOS scores than players without previous hamstring injuries. This indicates that complaints and symptoms of the posterior side of the thigh appear to be long lasting. Although fibrosis after hamstring injury is reported not to be associated with a higher risk of recurrence, long-term structural and functional changes might explain why players report symptoms and complaints 12 months after returning to competition [29]. These structural changes, for example, non-functional scar tissue and functional limitations, are associated with, among others, reduced flexibility, decreased sprint speed, and alterations in muscle tissue lengthening mechanics, biomechanics, and peak knee flexor torgue, [16,30–33].

Players who sustained a new hamstring injury had lower HaOS total and subdomain scores at baseline than players who did not sustain a new hamstring injury. Although there is no strong evidence for risk factors other than previous injuries, subdomains of the HaOS appeared to be associated with future hamstring injury. To our knowledge, the association between primary hamstring injury and pain and soreness in relation to activity and quality of life has not been investigated, although experts in the field do mention 'no pain' as a criterion for a safe return to play and for preventing recurrent hamstring injury [28,34]. Thus lower HaOS total and subdomain scores at the start of a season might be associated with an increased probability of new hamstring injury during the season. Furthermore, the risk of hamstring injury increased with both lower HaOS scores and higher number of previous injuries. This finding was expected based on previous research into recurrent hamstring injuries, where discomfort during sport-specific activities and pain were criteria for determining eligibility for return to play [28,34].

Previous studies have used a HaOS cut-off score below 80% to classify players at high risk of hamstring injury. Our logistic regression models showed that with a cut-off score of 80%, the probability of sustaining a hamstring injury in one season increased with the number of hamstring injuries in the previous season, going from 11% with no previous injuries, to 18% with one previous injury, and 28% with two previous injuries. This risk increased strongly with a lower score on the HaOS and the number of previous injuries. Although the HaOS score and previous injury have prognostic value, predicting future hamstring injury is not possible [10]. This is illustrated by our finding that a HaOS score of 0% combined with two previous hamstring injuries resulted in a probability of 76% of sustaining a new injury. It should be noted that in our dataset HaOS scores ranged from 29% to 100%, with 32 players (9%) having scores below 60%, 54 players (15%) having scores below 70%, and 98 players (28%) having scores below 80%.

Previous hamstring injuries have been recognized as evident risk factors for new hamstring injury. However, not every player with a history of hamstring injury gets reinjured, and no previous injury does not mean you are not at risk for hamstring injury. With the combination of number of previous injuries and the HaOS score, a first step towards the complex systems approach is set[35]. Multiple factors (or domains as measured by the HaOS) can interact in a certain way causing an increased risk or protect a player from injury[35].

Up till now, we recommend that all players participate in hamstring injury prevention programs. In the future, it might be possible to target prevention programmes at those players at greatest risk. This is important because it might increase programme participation and compliance, which have been shown to increase the effectiveness of these interventions [7,8,12,13].

This is the first study to investigate the association between the HaOS score and both previous and new hamstring injuries and to assess its prognostic value. The data for this study were collected prospectively during a large nationwide cluster-RCT that included 400 adult male soccer players [24]. The majority of the players (89%) filled in the HaOS at baseline and reported hamstring injuries weekly during one season. Unfortunately, the HaOS was only filled in at the start of the season, which might have led to missing valuable information during the season, especially right before the injury occurred. Previous hamstring injuries were registered retrospectively over a period of 12 months at the start of a new soccer season. This might have resulted in a recall bias, which could result in overestimation or underestimation of the number of previous hamstring injuries. While the current hamstring injuries were verified by the medical staff (physical therapist or sports masseur) of the teams, they were not confirmed with ultrasound or MRI.

To gain insight in individual changes in injury risk over time, future research could include longitudinal monitoring of symptoms with the HaOS. However, hamstring injuries are a multifactorial problem, and a multifactorial approach to their prevention and treatment is needed [36]. This hamstring injury model is the first step in targeted prevention, but other factors should be taken into account and tailored prevention programmes should be designed.

CONCLUSION

Amateur soccer players with a previous hamstring injury had lower HaOS total and subdomain scores than did non-injured players, as did players with new hamstring injuries in the current season. Thus HaOS scores and previous injuries appear to be prognostic factors for new hamstring injury. Logistic regression models can be used to estimate the probability that individual amateur soccer players will sustain a hamstring injury.

PRACTICAL IMPLICATIONS

The HaOS can be used to screen players at risk of hamstring injuries, based on symptoms, soreness, pain and symptoms during (sport-specific) activities, and quality of life. In this study, we found that lower scores on the HaOS and more hamstring injuries in the past were associated with new hamstring injuries. The prognostic value of the HaOS increased when it was used in combination with information about the number of previous hamstring injuries. The HaOS can thus be used to help staff to decide whether preventive measures should be incorporated in training.

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Conflict of interest

The authors declare that they have no conflicts of interest relevant to the content of this article.

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General Discussion

The aim of the studies presented in this thesis was to bring the prevention of primary and secondary hamstring injuries a step closer to the solution. Since effective hamstring injury prevention programs are available[1–3], we hypothesized that the annual increase in the incidence of hamstring injuries could be because very little is known about modifiable risk factors for these injuries and that these factors are not targeted in hamstring injury prevention programs. Therefore, we assessed new off-field risk factors and developed and tested a hamstring injury prevention program that targets multiple proposed risk factors (Figure 1)[4–8]. Furthermore, we assessed the effectiveness of plyometric training on performance, developed a better understanding of compliance issues, reviewed definitions of, and criteria for, return to play, and assessed the Hamstring Outcome Score as prognostic factor. In this overall discussion, we discuss the main findings and their practical implications, and provide future perspectives.

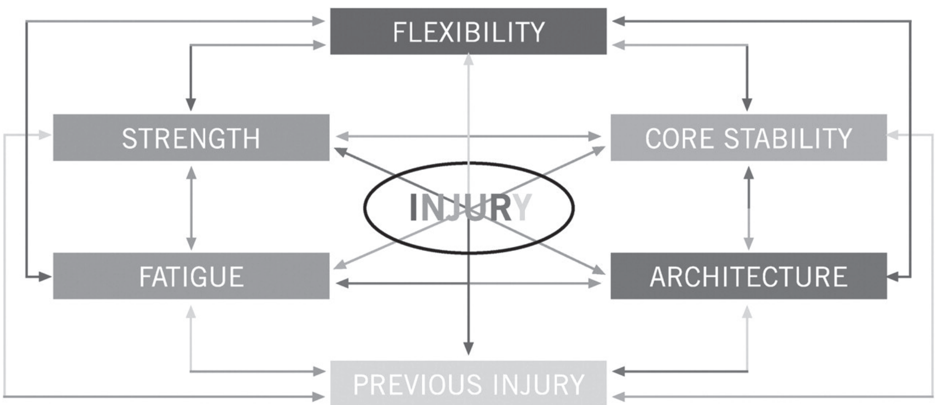

Figure 1. *Conceptual model for hamstring strain injury. Adapted from Mendiguchia et al., (2012)*[4]

RISK FACTORS

it is assumed that injuries only occur in players who are predisposed by internal risk factors, then exposed to external events or factors which cause a susceptible athlete, and then an inciting event occurs that leads to an injury [9]. As amateur soccer players often combine their sport with work or education, we investigated new risk factors for hamstring injuries, based on the assumption that activities in daily living cost energy and can disturb the balance between load and recovery, which may render an athlete susceptible to injury [10]. For example, heavy daily activities can increase general fatigue but also local fatigue in the lower extremity[10,11]. Lower extremity fatigue leads to a decrease in hamstring muscle strength, [11] which in turn probably leads to muscle compensatory mechanisms and kinematic strategies to maintain performance and protect the hamstring muscles during sprinting[12]. These compensatory changes, which may be indirectly caused by daily activities, can increase the risk of hamstring injuries in susceptible athletes. Therefore, we investigated the association between daily life factors and hamstring injury during one soccer season.

The factors work duration (hours), study duration (hours), traveling time (hours), sleep (hours), energy expenditure per week (0-10), previous hamstring injury (number) and new hamstring injuries were assessed in 399 male amateur soccer players. The only evident association was between previous hamstring injury and a new hamstring injury **(chapter 2)**.

In other words, no off-field risk factors were significantly associated with new hamstring injuries. Although there is only limited evidence for the role of on-field risk factors assessed at baseline, it seems that on-field risk factors are a more important target for hamstring injury prevention strategies. One such on-field risk factor is an eccentric strength deficit, which is frequently associated with hamstring injuries[13,14]. For instance, an increase in eccentric strength as a result of performing the Nordic Hamstring Exercise (NHE) [15,16] resulted in a 66-70% decrease in the incidence of hamstring injuries in both elite and amateur soccer players[17,18]. Although these results are internationally recognized, the incidence of hamstring injuries has not decreased in the past decade but has instead increased annually[19].

ADHERENCE ISSUES FOR THE NHE

Low adherence to injury prevention programs is considered the main reason for the lack of a decrease in the incidence of hamstring injuries[20]. This is a major issue when implementing primary preventive measures for (amateur) soccer players. Adherence to the NHE as injury preventive measure was very low among elite soccer players [20]. Reasons given for the poor adherence were doubts about the effectiveness of injury prevention programs and concern that preventive interventions increase the risk of injury and decrease performance[21].

The annual increase in hamstring injury incidence and low adherence to injury prevention strategies among elite soccer players prompted us to investigate the long-term adherence to the NHE among amateur soccer players and provide an overview of arguments for not performing the NHE program **(chapter 3)**. The main results showed that 2 years after the completion of an RCT, 69% of the high-level amateur soccer players reported never performing the NHE program and only 3% reported that they always performed it.

Players, technical staff, and medical staff were asked why the NHE program was not performed as preventive measure. Players reported knowledge about 'effectiveness of the NHE' and 'personal motivation' for injury prevention measures as reasons. The technical staff also mentioned these reasons and added 'knowledge of the NHE'. The medical staff mentioned these reasons as well and added 'consensus within staff'.

Thus, players' motivation, knowledge of the program and its effectiveness, consensus between staff members,[22] and performance improvement[21] should be considered when implementing primary preventive programs for amateur soccer teams.

NEW INJURY PREVENTION PROGRAM – PLYOMETRIC TRAINING

Concerns about the effectiveness of programs and knowledge of these programs can probably be overcome by using appropriate communication methods once the effectiveness of a program has been established. It will probably be more difficult to address player and staff motivation and consensus among staff because these are dependent on personal characteristics and beliefs. Motivation is defined as the energizer of behavior in pursuit of a goal, a fundamental element of our interaction with the world and each other[23]. To overcome the limitations in motivation and consensus among staff, we proposed that (1) prevention programs should also increase performance (collective goal) and that (2) exercises should be easy to incorporate in training, in order to make it easier for all stakeholders (coaches, medical staff, and players) to include preventive interventions in training sessions and to adhere to them[21,22,24]. Because there is uncertainty about who is ultimately responsible for injury prevention,[25] the medical staff was held responsible for execution of the injury prevention program and for reaching consensus with coaches and players in our study.

Plyometric training is a recognized type of training to improve performance in team sports. While this type of training is thought to improve soccer performance, there is no strong evidence for this as yet. However, given its characteristics, plyometric training should be appropriate for improving performance and preventing injury [26–30].

Because improved performance could be a motivator for adherence for injury prevention programs and plyometric training has the potential to reduce the number and severity of hamstring injuries, we systematically reviewed the effects of plyometric training on soccer-specific activities. The main results showed that soccer players who followed plyometric training had a significantly greater jump height, sprint speed over 20 m, and endurance. An absence of evidence was found for strength, sprint speed over other distances, and agility **(chapter 4)**. The absence of evidence for the last-mentioned outcomes can be explained by the differences in the design of plyometric training programs, the type of training used as comparator, , the population studied, and the methodological quality of studies included in the review.

BOUNDING EXERCISE PROGRAM

Given the performance-enhancing effects of plyometric training, the Bounding Exercise Program (BEP) was designed and evaluated in the studies reported in **chapters 5 and 6**. The main results showed an absence of evidence for a preventive effect of the BEP.

One of the reasons for this lack of preventive effect on hamstring injury occurrence, was poor quality of execution of the BEP. The BEP aimed to reach maximal horizontal speed in order to achieve the greatest possible eccentric hamstring contraction [31,32]. If players fail to achieve maximum horizontal speed, they will probably not benefit from the BEP. In addition, we could not individualize the training dose. Although we followed general recommendations for the number of repetitions and rest in between series, the intensity of exercise may depend on the correctness of BEP execution but also on individual characteristics, such as weight and physical fitness. Even though there was a progressive build- up of the exercises over the study period, the intensity of the exercises was probably not the same for each participant. To assess the dose-response relationship of the BEP, we completed a pilot study. Although players' performance improved on the side step cutting protocol[33] and countermovement jump after 12 weeks of BEP, there were substantial individual differences (unpublished data).

In using the BEP, we aimed to reduce hamstring injury risk by targeting multiple risk factors for hamstring injuries, according to the model of Meeuwisse et al.(2007)[34] (figure 2). This model assumes that factors such as muscle architecture, strength, intermuscular

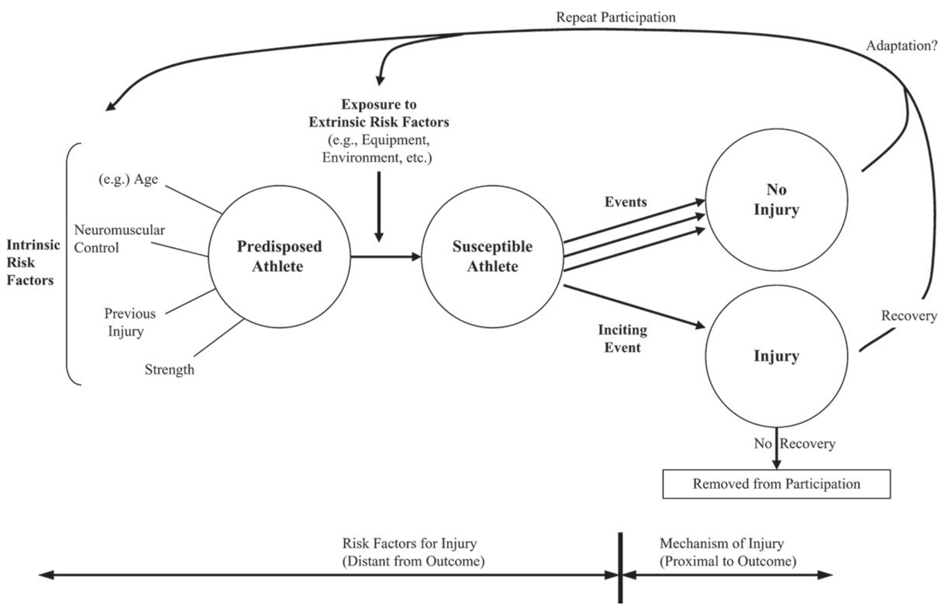

Figure 2. *A dynamic model of etiology in sports injury. Adopted from Meeuwisse et al.[34]*

coordination, endurance, and core stability are inter-related and determine the risk of injury[35–37]. Although the BEP was designed to affect the proposed risk factors[4] strength, fatigue, core stability, and architecture, flexibility and previous injuries were not taken into account. Furthermore, several other risk factors could be added to the multifactorial hamstring injury model, such as intermuscular coordination[35], optimal biomechanics during running, changing direction and sprinting,[38,39] psychological factors, and other risk modifiers (i.e. timing in the match or soccer season, importance of the player, importance of the match) [40].

PLAYER MOTIVATION FOR INJURY PREVENTION EXERCISE PROGRAMS

The BEP was designed to take little time and effort to perform during training sessions. It takes only 3 to 5 minutes per session, is easy to incorporate in training, and uses a type of training that can improve sport-specific activities. Although the BEP was designed to overcome the barriers 'personal motivation' and 'consensus between staff members', compliance decreased during the soccer season. The aim of the study described in **Chapter 7** was to gain insight into the motivators and barriers to injury prevention exercise programs, and the BEP in particular.

The relationships between player characteristics and perceptions, and adherence to the BEP were analyzed. Player characteristics that were associated with greater adherence were older age and more years of soccer experience. Contrary to our expectations[41], previous hamstring injury and hamstring injury during the soccer season were not significantly associated with BEP adherence. According to the health beliefs model, players with a previous hamstring injury would be expected to be more willing to act to prevent new hamstring injuries, because they have experienced the problem and its consequences and are more susceptible to re-injuries [42–44]. Our data, although with low power, did not confirm this. Factors that might have affected these outcomes are perceived severity of, and perceived susceptibility to injury, perceived barriers to the injury prevention programs and perceived self-efficacy.

Players who had a better adherence to the program perceived the BEP as being useful, less intense, more functional, or less time-consuming than did the players who had a poorer adherence. Program difficulty or intention to use it the next season were not related to better adherence. These results were in line with the categories 'perceived benefits' and 'perceived severity' reported in the health beliefs model [42]. When players believe they are at risk of sustaining a severe injury and believe that they would benefit from the program, then they adhere to it. Therefore, personal motivation is an important factor to consider when designing and implementing an injury prevention exercise program for soccer players.

Factors that were not included in this study were other stakeholders, such as coaches and medical staff, and the dynamics between staff members, staff and players, and within the team. The role of the motivation of staff and agreement between technical and medical staff has already been described[22]. Theories about these group dynamics can be adopted from social psychology. One such theory is social proof [45]. Social proof works best when there is uncertainty about what is right. People are more likely to behave like their peers when they are not sure whether what they do is the right thing to do. For injury prevention exercise programs, this means that when there is uncertainty among users about whether a program is beneficial or not, if a few players perform the exercises, others are likely to follow their lead. The smaller the group, the more important the behavior of each individual player becomes (both positive and negative). Key players (i.e. the captain and more experienced players) tend to be important in this process, since people are more likely to follow their leaders.

RETURN TO PLAY

If adherence to injury prevention exercise programs remains low, then previous injury is the evident risk factor for new hamstring injury. Moreover, not every hamstring injury can be prevented. Thus return-to-play (RTP) decision-making becomes important to prevent the injury-reinjury cycle.

RTP models have been developed in the past decade. Creighton et al. developed a RTP decision model based on health risk, activity risk, and risk tolerance[46]. This model includes physical, psychological, and environmental aspects of RTP decision making. However, no clear definition of RTP was available nor were there RTP criteria for players after a hamstring injury. Our qualitative systematic review about RTP definition and criteria showed that RTP could mean return to pre-injury level, return to match play, return to training, return to full activity, or completed rehabilitation. In addition, we found a wide variety of criteria for determining RTP[47] **(Chapter 8)**.

Differences in RTP definition result in different endpoints for rehabilitation. Does a player RTP when he ready to participate in training, when he is ready for match play, when his physical condition returns to a preinjury level, or when his performance returns to a pre-injury level? The consensus statement of 2016 concerning RTP described return to participation, return to sport, and return to performance[48]. In this statement, return to participation stands for return to rehabilitation, training, sport at a lower level; return to sport stands for return to his sport, but not at the desired level; return to performance exceeds return to sport and stands for return to the preinjury level of performance[48]. Another consideration with regard to rehabilitation is the control-chaos continuum[49]. This continuum aims to provide the clinician with guidance in progressing rehabilitation from highly controlled situations to 'chaotic' situations, referred to as when the player starts training again.

The RTP decision is a dynamic process that is influenced by the environment and timing in the season[50]. In other words, beside physical and psychological factors, the RTP decision is about the balance between risk factors and risk tolerance [50]. How much risk a player, coach, or team are willing to take differs throughout the soccer season and depends on multiple environmental factors, such as the importance of the player, the importance of the match, or the importance of the sponsors.

Once RTP has been defined, criteria can be added to the endpoint (return to performance) [48]. Our systematic review extracted criteria in five categories: absence of pain, similar strength, similar flexibility, functional performance, medical clearance, and other. These categories were further expressed in worldwide Delphi studies and consist of absence of pain, similar flexibility, strength, psychological readiness, or players' confidence, performance on field testing, and medical clearance[51,52].

One of the main questions arising from these studies[51,52] is how to measure these criteria and to establish cut-off values to ensure players do not sustain a new injury. These criteria probably change over time, as the fitness of players changes throughout the soccer season. This implies that soccer players should be tested frequently in order to establish their preinjury level.

PREDICTING INJURY RISK AND TARGETED PREVENTION PROGRAMS

Prerequisites for targeted prevention are an adequate screening tool and specific prevention programs that complement the risk profiles established on the basis of screening results. The value of screening for injury risk is debated in sports medicine research[53]. While the Wayser-Jung criteria can be used to develop a screening program for hamstring injuries,[54] several limitations arise in stages 2 – 4, which are: there is a detectable early stage (stage 2), treatment in an early stage of injury is more beneficial than treatment in a later stage of injury (stage 3), and there is a validated test to detect early stages of hamstring injury (stage 4) [54]. Currently, we cannot detect early-stage hamstring injury (stage 2) because there are no validated markers of early injury, which means treatment in an early stage is not possible and no validated tests to detect the early markers for hamstring injury are available (stages 3-4).

A difficulty with the early detection of hamstring injuries is that the risk of hamstring injury is probably dynamic system and changes from time to time. Screening tests are currently carried out once, at the start of the soccer season. If screening tests were carried out more frequently, then it might be possible to determine the dynamic character of the risk of hamstring injury and early markers of that risk.

Although at the moment there are no recognized early signs and symptoms of hamstring injuries and no instruments to detect them, there are symptoms that are associated with hamstring injury, such as soreness, decreased flexibility or strength, decreased sports performance, and pain during (sport-specific) activities[51,55,56]. These anamnestic cues might help focus attention on injury prevention strategies for affected players. No validated screening tool is available, but the Hamstring Outcome Score (HaOS) provides insight into several anamnestic cues. The HaOS consists of five domains: pain, soreness, symptoms, pain during sport-specific activities, and quality of life, and is used in research to classify players as being at high or low risk of hamstring injury and to evaluate symptoms after hamstring injury[57,58]. The study described in **chapter 9** investigated the prognostic value of the HaOS for predicting hamstring injuries in the subsequent soccer season. The main finding was that the HaOS is associated with both previous and new hamstring injuries and can provide soccer players with insight into their own injury risk when used in combination with the number of hamstring injuries previously sustained by the player.

The lack of knowledge about early markers and validated tests to screen for hamstring injury does not mean that clinicians and researchers should not try to prevent hamstring injury and not screen for potential risk factors[53]. The results of the HaOS study provide players and staff with insight into the risk of hamstring injury, based on self-reported signs and symptoms of the players, but more research is needed to develop a hamstring injury screening tool. Firstly, self-reported signs and symptoms can be biased by socially desirable answers. This bias probably increases when the stakes are higher (i.e. championship matches). Secondly, a three-step sequence is needed to develop screening tools: 1) determining the relationship between the marker and injury risk, 2) determining test properties, and 3) an intervention based on this screening test should be more effective than the regular preventive measures[53]. Our study about the prognostic value of the HaOS is the first step in this three-step sequence for developing a screening test to predict the hamstring injury risk of soccer players.

When considering the prevention of hamstring injuries in amateur soccer players, three types of potentially useful factors should be considered: (1) on-field sport-related risk factors, (2) off- field risk factors, and (3) signs and symptoms of early-stage hamstring injuries. Two of these three types of risk factors were investigated separately in this thesis. It would be interesting to combine the three factors in a large observational cohort study with frequent assessment intervals.. In this way, it might be possible to determine the interaction between the separate factors and so make a further step in explaining why not every player that possesses a certain risk factor sustains a hamstring injury.

NEW VISION ON THE HAMSTRING INJURY PROBLEM

The future of hamstring injury prevention lies in personalized and targeted injury prevention. Hamstring injuries are a multifactorial problem and hamstring injury prevention is more than the sum of its parts. All factors associated with hamstring injuries affect each other in a positive or a negative way. In other words, not all players with the same risk factor have a similar risk of hamstring injury. The injury risk is affected by multiple other factors that are or are not present in an individual player.

Worldwide, research groups are focusing on different parts of the hamstring injury risk problem. These groups are looking into biomechanics, strength, flexibility, functional outcomes, sport-specific outcomes, psychological factors, or risk modifiers (i.e. environmental factors such as timing in the match/season, field conditions, importance of the player and the match). Hamstring injury risk could also be considered as a network of factors that influence whether a player sustains a hamstring injury or not. Not every player with a previous hamstring injury gets reinjured. Why not? Probably because other factors affect the risk of injury. Once all the parameters affecting the chance of getting a hamstring injury have been identified, a start can be made to the development of a hamstring injury risk network (figure 3).

This model incorporates different factors:(1) sport-related physical risk factors, (2) off- field risk factors, (3) signs and symptoms that might be present in early stages of hamstring injuries, (4) psychological factors, and (5) risk modifiers (e.g. field condition, timing in match/season). These factors can affect each other and change over time, creating a dynamic network. Moreover, these factors may interact differently in individual players. This is why such networks must be developed by medical staff for each player and should be evaluated frequently.

All factors (nodes) should be measured with valid instruments, and the predictive value (line thickness) of each factor needs to be determined. The outcome of this network (i.e. the most influential nodes and thickest lines) might be helpful for deciding which intervention would be most effective for preventing a hamstring injury in a specific player. This means a personalized prevention plan, based on evidence-based information, should be developed. Consider:

- prescribing the NHE for players with eccentric strength deficits,
- optimizing sprint mechanics for players with non-optimal movement deviation patterns,
- plyometric exercises for players with unstable chain kinetics to improve intermuscular coordination and joint stiffness.

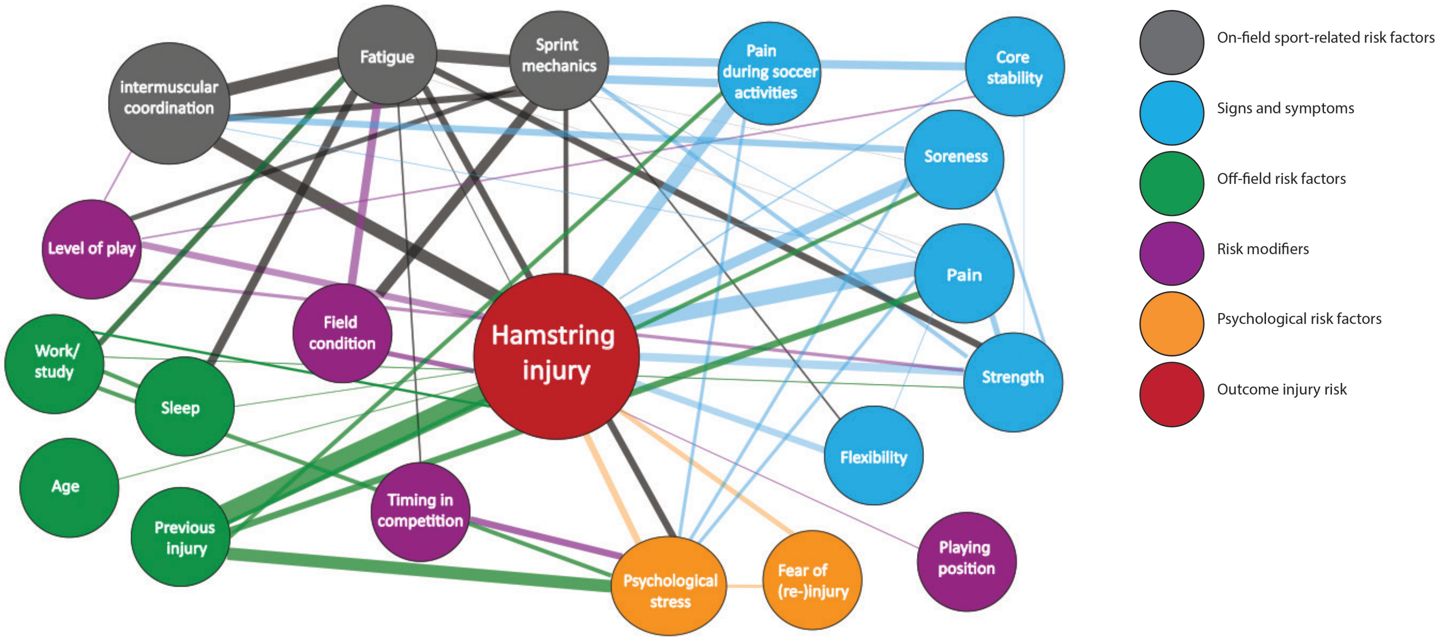

Figure 3. *Example of a hypothetical network associated with the risk of hamstring injury. The thickness of the connecting lines represents the strength of the relationship between the nodes.*

This approach is more complex than a generalized prevention plan. However, an individual targeted preventive approach has both advantages and disadvantages, as general preventive measures have. A challenge in targeted prevention is that it is more complex and players probably do not have time to perform interventions during soccer training, unless coaches are willing to make time for them. A major advantage is that interventions are designed for the individual player, so this overcomes the idea of doing useless exercises, which is an often-mentioned argument for non-compliance with injury prevention exercise programs[21,22]

It is important to think about implementation strategies during the development of injury prevention strategies. The Re-AIM framework could be helpful here[59]. For instance, a way to 'reach' most male amateur soccer players is to ensure that injury prevention interventions and tests are easy and fast to do. National football associations can play a central role in the dissemination of intervention programs. In the Netherlands, the Royal Netherlands Football Association (KNVB) could ensure that such programs are incorporated in coach education and that there are online repositories of relevant exercises. This could be integrated into on-line tools such as Rinus (https://rinus.knvb.nl/), where coaches can find information that is related to coaching and training soccer teams, including tests, complete training sessions, and preventive measures.

FUTURE RESEARCH

Future studies should focus on frequently measuring off-field activities as risk factors during the soccer season, so that changes over time can be measured in relation to the occurrence of hamstring injuries. This will make it possible to establish whether hamstring injuries are associated with the dynamic character of physical and psychological load off the football field, as has been hypothesized. Such a cohort study may identify on-field and off-field risk factors. Before conducting these large longitudinal studies, instruments to detect and evaluate potential risk factors need to be validated. During such a study, risk factors and return to performance criteria should be validated and risk networks could be plotted.

Besides identifying players at risk by plotting risk networks and using targeted prevention to increase adherence, another focus could lie in group dynamics. Insight into team dynamics and communication within staff, and between staff and players, is needed to understand group dynamics when introducing injury prevention programs effectively. Qualitative studies or mixed methods designs would seem appropriate to determine which stakeholders and how many players should be targeted in order to ensure that teams adhere to preventive programs.

Plyometric training can still play a role in targeted injury prevention programs, but more needs to be learned about the dose-response relationship. In addition, consensus should be reached about the choice of training parameters and in how interventions and results are reported. When designing a randomized controlled trial focusing on the dose-response relationship of plyometric training, the quality of movement should be monitored in a standardized way.

Lastly, a large randomized controlled trial incorporating the network approach and individual evidence-based injury prevention programs will be needed to determine the expected benefits of this individual approach compared with a generalized injury prevention approach.

WHAT CAN BE LEARNED FROM THIS THESIS?

- Off-field activities measured at baseline are not associated with the occurrence of hamstring injuries. Thus, the assessment of off-field activities once at the start of the season is not recommended as a way to determine the potential risk of hamstring injuries. However, if these activities are assessed frequently throughout the soccer season in amateur soccer players, it might be valuable to monitor load and recovery outside playing/training hours (i.e. during daily life and recreation).

- Adherence to an effective hamstring injury prevention program, such as the Nordic Hamstring Exercise (NHE), is low. Arguments for this low adherence are lack of knowledge of the program, no personal motivation of players and staff, and no consensus within staff.

- Plyometric training can increase jump height, 20-m sprint speed, and endurance in male amateur soccer players, but there is a need for high-quality studies to verify the effects of plyometric training in soccer players.

- The bounding exercise program (BEP) in its current form does not reduce the incidence of hamstring injuries in male amateur soccer players significantly. Possible reasons for this include a poor quality of movement during execution of BEP, intensity of the program, and compliance throughout the soccer season. At the moment, it is advised that the NHE be incorporated in regular training sessions.

- Adherence to injury prevention programs such as the NHE and BEP is low. When implementing an injury prevention program, efforts could focus on older and more experienced players because these players are likely to be early adapters. When designing an injury prevention program, it should be kept in mind the more useful and functional, and the less intense and time consuming the players perceive the injury prevention program, the better they adhere to the program.

- Return-to- play definitions in the literature include return to pre-injury level, return to match play, return to training, return to full activity, or completed rehabilitation. Return-to-play criteria mentioned in the literature can be divided into categories: absence of pain, similar strength, similar flexibility, functional performance, medical clearance, and other.

- There are currently no validated tests or tools to adequately screen for the risk of hamstring injury. Therefore, the Hamstring Outcome Score (HaOS) should be studied further in this context. However, it is known that players with a previous hamstring injury are at higher risk of new hamstring injury than players without a previous hamstring injury. The HaOS in combination with the number of previous hamstring injuries can provide players and staff with insight into the risk of hamstring injury in individual players. This knowledge might stimulate players to perform preventive programs.

- The Royal Netherlands Football Association could incorporate the NHE in their coach education plans and create an active implementation plan, according to the Re-AIM framework, to incorporate the NHE in regular training sessions. Furthermore, the Royal Netherlands Football Association, Society of Sports Physicians, sports physical therapists, and sports masseurs could play a key role in promoting the frequent screening of off-field activities, the use of the HaOS, and the use of return-to-performance criteria, by communicating results to members and colleagues.

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A

Summary
Nederlandse samenvatting
Dankwoord
About the author

SUMMARY

Hamstring injuries are the most common muscle injuries in male amateur soccer players and cause long absence of play. In the past decade a lot of research has been done to prevent this severe muscle injury. Unfortunately, this has not yet resulted in a decrease of hamstring injury incidence. Therefore, the aim of this thesis was to investigate both primary and secondary hamstring injury prevention in order to decrease the incidence and severity of hamstring injuries in male amateur soccer players.

Hamstring injury prevention strategies that are used in professional soccer are often translated to amateur soccer. However, there is a difference between amateur and professional soccer in daily life. While professional soccer players can focus on their sport completely, amateur soccer players work or study during the day and sometimes practice other sports which may result in differences in workload and recovery over the week. In **chapter 2** we investigated the relation between off-field factors and hamstring injury risk. This chapter shows no relation between off-field activities and increased hamstring injury risk, but did confirm that a previous hamstring injury is a risk factor.

The Nordic Hamstring exercise (NHE) is an evidence based effective hamstring injury prevention program. Nevertheless, no injury incidence reduction has been seen yet. **Chapter 3** describes the adherence for the NHE two years after a nationwide RCT was concluded and reasons to (not) perform this program. Only 4% of the players adhered to the NHE as prescribed in the RCT. Players mentioned motivation and knowledge of the program to (not) perform the NHE. Coaches and medical staff agreed with these reasons and added effectiveness of the program. Medical staff also thought that consensus within staff is an important reason to (not) perform the NHE.

Since the adherence for the NHE is low, and other studies suggest that injury prevention programs do not consist of sport-specific exercises, plyometric exercises were proposed to prevent hamstring injuries. An added benefit might be that plyometric exercises may improve soccer-specific performance. Therefore, a systematic review and meta-analysis was executed to describe the effects of plyometric training on soccer specific performance outcomes (**chapter 4**). This meta-analysis showed that plyometric training increased jump height, sprint speed over 20m and endurance.

In **chapter 5** (study protocol) and **chapter 6** (study results) the study design and results of the cluster-RCT investigating the preventive effect of the Bounding Exericse Program (BEP) were described. The BEP is a 12-week built-up program consisting of 'walking lunges', 'triplings and droplunges' and 'bounding'. After the 12-week built-up period, players were expected to perform the BEP throughout the competition. Chapter 6 showed an absence of evidence for a preventive effect of the BEP on hamstring injuries in male amateur soccer players. Besides that, the adherence decreased during the competition.

Although the BEP was designed to overcome the reasons for not performing injury prevention programs, the adherence decreased during the competition. Therefore, the relation between (1) player characteristics and adherence to BEP and (2) the relation between player perceptions of the program and adherence to BEP were investigated in **chapter 7**. The results indicated that older players, with more years of soccer experience adhered better to the BEP than younger players with less years of soccer experience. Previous hamstring injury and educational level were not related to adherence. Player perceptions such as usefulness, functionality, intensity, and time-consummation were associated with adherence to BEP, while difficulty and intention to continue the program in the following competition were not associated with adherence to BEP.

Despite effective hamstring injury prevention, not every hamstring injury can be prevented. Therefore, it is important to prevent recurrent hamstring injuries by clear return to play criteria. In the past years, several definitions of return to play are used to study return to play criteria. In **chapter 8** we described the available definitions and criteria for return play after hamstring injury in a qualitative systematic review. The definitions include 'return to preinjury level' and 'return to full activity'. The return to play criteria were categorized in 'no pain, similar strength, similar flexibility, functional performance and medical staff clearance'.

Adherence to hamstring injury prevention exercise programs remains low. A strategy to increase adherence to injury prevention programs is to target the injury prevention programs on the players that are at higher risk for injury. Therefore, the hamstring outcome score (HaOS) is investigated in **chapter 9**. The HaOS is a questionnaire that addresses symptoms that are related to hamstring injuries. The results of this study showed that the HaOS score is related to both previous and new hamstring injuries. The main result of this study is that the probability of a hamstring injury at an 80% score on the HaOS increases from 11% (0 previous hamstring injuries) to 18% (1 previous hamstring injury) to 28% (2 previous hamstring injuries).

This thesis ends with a general discussion in **chapter 10**. In this chapter we discussed all main findings about off-field risk factors, plyometric training as a measure for performance enhancement and hamstring injury prevention, adherence to injury prevention programs, return to play and prognostic factors. Additionally, we provided practical implications and future research directions. The future of hamstring injury prevention should focus on determining the complex, dynamic interactions between (potential) risk factors. These factors interact with each other and change over time, therefore the probability of hamstring injury changes over time as well. Additionally, targeted and individualized injury prevention programs should be developed. Therefore, adequate screening tools must be developed and the individualized prevention programs should be developed and evaluated with consideration of the complex, dynamic character.

NEDERLANDSE SAMENVATTING

Hamstringblessures zijn de meest voorkomende spierblessures bij mannelijke amateurvoetballers en zorgen voor langdurig sportverzuim. Daarom is in de afgelopen jaren veelvuldig onderzoek gedaan naar het voorkomen van deze specifieke spierblessure. Echter, tot op heden is er nog geen afname van het aantal hamstringblessures gerealiseerd. Het doel van dit proefschrift was om zowel primaire als secundaire hamstringblessurepreventie te onderzoeken ter vermindering van het aantal hamstringblessures bij mannelijke amateurvoetballers.

Veelal worden preventieve maatregelen die toegepast worden in het professionele voetbal, vertaald naar het amateurvoetbal. Echter een verschil tussen de professionele voetballers en amateurvoetballers is de invulling van het dagelijks leven naast het voetballen. De werk- en/of studiebelasting, reistijd en andere sporten van amateurvoetballers zouden mogelijk een verstoring bewerkstelligen in de balans tussen belasting en herstel. In **hoofdstuk 2** werd de relatie tussen factoren buiten het veld en het ontstaan van hamstringblessures onderzocht. Hier werd beschreven dat in deze groep amateurvoetballers er geen bewijs is voor een relatie tussen activiteiten buiten het veld en het ontstaan van een hamstringblessure. Wel werd bevestigd dat een eerdere hamstringblessure, een verhoogd risico geeft op een nieuwe hamstringblessure.

Preventieve maatregelen worden met name op het veld genomen. De Nordic Hamstring Exercise (NHE) is een bewezen effectieve maatregel om hamstringblessures te voorkomen. Desondanks, is er tot op heden geen afname van het aantal hamstringblessures bewerkstelligd. In **hoofdstuk 3** werd onderzocht hoeveel de NHE 2 jaar na de onderzoeksperiode nog werd toegepast en wat argumenten zijn om dit programma wel of niet uit te voeren. De NHE bleek slechts door 4% van de ondervraagden volgens voorschrift te worden uitgevoerd. Spelers benoemden persoonlijke motivatie en kennis van het programma als argumenten om de NHE wel of niet uit te voeren. Coaches en medische staf benoemden dit ook en voegden effectiviteit van het programma toe. Medische staf vond overeenstemming binnen de staf eveneens een belangrijk argument.

Omdat de NHE nauwelijks werd uitgevoerd in de dagelijkse voetbalpraktijk en andere studies aangaven dat huidige preventieve programma's niet sport-specifiek genoeg waren, werd voorgesteld om plyometrische oefeningen in te zetten ter preventie van hamstringblessures. Een bijkomend voordeel van een dergelijk programma zou ook de prestatie bevorderende effecten zijn. Daarom werd in **hoofdstuk 4** eerst een systematische review uitgevoerd naar de effecten van plyometrisch trainen op voetbal-specifieke uitkomsten. Uit de meta-analyses kwam inderdaad naar voren dat plyometrisch trainen een positieve invloed heeft op spronghoogte, op sprintsnelheid over 20m en op het uithoudingsvermogen.

In **hoofdstuk 5** (studieprotocol) en **hoofdstuk 6** (studieresultaten) werden de opzet en resultaten van een cluster-gerandomiseerde gecontroleerde trial naar het preventieve effect van het Bounding Exercise Programma (BEP) beschreven. Het BEP is een oefenschema met een 12 weken opbouwprogramma en een onderhoudsprogramma. In 12 weken werd gedoseerd opgebouwd naar loopsprongen over een afstand van 30 meter. Na de 12 weken opbouw werden de spelers geacht om het bounding gedurende de gehele competitie uit te voeren in de trainingen. Er bleek geen preventief effect van het BEP op het ontstaan en de ernst van hamstringblessures bij volwassen mannelijke amateurvoetballers. Daarnaast was er gedurende de looptijd van de studie een afname in adherentie gevonden.

Hoewel het BEP ingericht was om barrières voor het uitvoeren van preventieve oefenprogramma's uit de weg te nemen, is eveneens een daling in mate van BEP-uitvoering waargenomen. Daarom is in **hoofdstuk 7** gekeken naar de relatie tussen 1) speler-karakteristieken en mate van uitvoering van het BEP, en 2) de relatie tussen ervaringen van spelers met betrekking tot het BEP en de mate van uitvoering van het BEP. De resultaten gaven aan dat oudere spelers en spelers met meer jaren voetbalervaring het BEP meer uitvoerden dan de jongere spelers met minder aantal jaren voetbalervaring. Een eerdere hamstringblessure en opleidingsniveau bleken niet van invloed op de mate van uitvoering. Daarnaast is gevonden dat percepties als het nut, functionaliteit, zwaarte van het programma en tijd geassocieerd zijn met mate van uitvoering. Daarentegen waren moeilijkheidsgraad en intentie om het programma de volgende competitie door te zetten niet gerelateerd aan adherentie voor BEP.

Ondanks een effectieve preventieve maatregel, kunnen niet alle hamstringblessures voorkomen worden. In de literatuur worden verschillende definities gebruikt voor terugkeer naar sport. Bij deze definities worden andere criteria gehanteerd. In **hoofdstuk 8** beschreven we in een systematische review de beschikbare definities en criteria voor terugkeer naar sport na een hamstringblessure. De definities in de literatuur beslaan 'terugkeer naar het niveau van voor de blessure' en 'uitvoeren van alle activiteiten'. De criteria werden gecategoriseerd in 'geen pijn, geen krachtsverschil, gelijke flexibiliteit, functionele prestatie en vrijwaring van medische staf'.

Oefenprogramma's ter preventie van hamstringblessures worden tot op heden weinig uitgevoerd. Een strategie om de mate van uitvoering te verhogen, is om interventies te richten op spelers die een verhoogd risico lopen. Daarom is in **hoofdstuk 9** de hamstring outcome score (HaOS) onderzocht. De HaOS is een vragenlijst naar symptomen die gerelateerd zijn aan hamstringblessures. De resultaten van deze studie lieten zien dat de HaOS score gerelateerd is aan eerdere en nieuwe hamstringblessures en dat de kans op een hamstringblessure bij een score van 80% op de HaOS toeneemt van 11% bij geen eerdere hamstringblessure, naar 18% bij 1 eerdere hamstringblessure, tot 28% bij 2 eerdere hamstringblessures.

De thesis werd afgesloten met een algemene discussie over de bevindingen van de studies in **hoofdstuk 10**. In dit hoofdstuk worden de belangrijkste bevindingen over risicofactoren, plyometrie ter prestatiebevordering en blessurepreventie, mate van uitvoer van blessurepreventieprogramma's, terugkeer naar sport en prognostische factoren bediscussieerd. Daarnaast worden praktische implicaties en adviezen voor toekomstig onderzoek beschreven. De toekomst van hamstringblessurepreventie zal zich moeten richten op het duiden van het complexe, dynamische geheel van (potentiele) risicofactoren die elkaar beïnvloeden en over de tijd veranderen, waardoor het risico op een hamstringblessure eveneens van tijd tot tijd verandert. Om vervolgens tot geïndividualiseerde gerichte preventieve maatregelen te komen, zullen zowel screeningstools als op maat gemaakte preventieve programma's ontwikkeld en getoetst moeten worden, met inachtneming van het complexe dynamische karakter van de hamstringblessure.

A

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A

ABOUT THE AUTHOR

Curriculum Vitae

Sander was born on May 25, 1987 in Rhenen, the Netherlands. After high school graduation at the Christelijk Lyceum Veenendaal, he started studying human movement sciences at the Free University, Amsterdam in 2007. After two years he found out that physiotherapy was what he actually wanted to do and continued his education at the University of Applied sciences, Utrecht. He graduated in 2012 following the Physiotherapy Bachelor plus program and started working at the primary physiotherapy practice Rembrandt Fysiotherapie en Revalidatie in Veenendaal, which is his primary employer ever since. At Rembrandt Fysiotherapie en Revalidatie his activities involve treating patients, supervising internships, participating in research projects as consortium partner (living lab) and collaborating in workgroups in a primary health care center to improve primary care. From 2012 till 2016 he additionally worked at a first class amateur soccer team (v.v. De Merino's) and from 2014 till 2017 at a team competing in the top class amateur competition and second division (GVVV).

In 2012 he started studying Clinical Health Sciences, Physiotherapy Science at Utrecht University. During this masters he additionally followed the courses 'Biophysical Concepts', 'Applied exercise physiology' and 'clinical exercise physiology' at the Free University, Amsterdam. For his master he contacted Prof. Dr. Frank Backx, who offered him an internship. His thesis, that focused on expert opinions about return to play after hamstring injury, was part of the HIPS study which was supervised by Dr Nick van der Horst. Sander graduated in 2014 with a master's degree from the university of Utrecht. After graduation he continued to work on a systematic review with Nick about return to play criteria.

In 2015 he was contacted to write a grant proposal with his supervisors, Prof Dr. Frank Backx and dr. Bionka Huisstede. After receiving the Grant he was awarded with a PhD position at the University Medical Center Utrecht on the department of Rehabilitation, Physical therapy science and Sports. During his PhD he combined his work as a PhD student at UMC Utrecht with his work as physiotherapist (Rembrandt Revalidatie & Fysiotherapie and soccer teams) and as a teacher (BSc physiotherapy at SOMT university of applied sciences).

PhD portfolio

Name PhD student:	Peter Alexander van de Hoef
Institute:	University Medical Center Utrecht Dep. Rehabilitation, Physical Therapy Science & Sports
PhD period:	01.04.2016 – 15-09-2020
Promotor:	Prof. dr. F.J.G. Backx
Co-promotor:	Dr. M.S. Brink

Courses

Basiscursus Regelgeving en Organisatie van Klinische trials (BROK), Nederlandse Federatie Universitair Medische Centra (NFU)	2017
Academic writing in English, Utrecht University	2018
Doelmatigheidsonderzoek: Methoden en Principes, EpidM	2018
Scientific artwork & infographics, Utrecht University	2019
Introduction to R, Utrecht University	2019

(Inter)national conferences - attendance

Dutch Sports Medicine Society annual congress, Ermelo (5x)	2016- 2019
Symposium sports injury prevention Veiligheid NL, Amsterdam (4x)	2016-2019
Symposium Injury prevention in football, Zeist	2017
Symposium Overload injuries in football, Utrecht	2018
Annual congress of the American College of Sports Medicine, Minneapolis, USA	2018

(Inter)national conference – Presentations

The preventive effect of the bounding exercise programme on hamstring injuries in amateur soccer players. American College of Sports Medicine, Minneapolis, USA	2018

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The preventive effect of the bounding exercise programme on hamstring Injuries in male amateur soccer players, Dutch Sports Medicine Society annual congress, Ermelo	2018
Plyometric training to reduce hamstring injuries in male amateur football players - A Cluster Randomized Controlled Trial. Science and Engineering Conference on Sports Innovation, Groningen.	2018
The effect of the bounding exercise program on hamstring injuries in male amateur soccer players. Symposium sports injury prevention VeiligheidNL, Amsterdam	2018
Hamstring injury prevention Strategies – Bounding Exercise Program. Symposium sports injury prevention VeiligheidNL, Amsterdam. 2016	
Hamstring injury prevention strategies and return to play. Symposium sports injury prevention VeiligheidNL, Amsterdam	2019
The effects of lower-extremity plyometric training on soccer-specific outcomes – a systematic review and meta-analysis, Dutch Sports Medicine Society annual congress, Ermelo	2019
HaOS or Chaos? The prognostic value of the Hamstring Outcome Score. Dutch Sports Medicine Society annual congress, Ermelo	2019

Poster presentations

The preventive effect of the bounding exercise programme on hamstring injuries in male amateur soccer players. Physical Therapy Science, Utrecht	2017
The hamstring Outcome Score as predictor for safe Return to play? Dutch Sports Medicine Society annual congress, Ermelo	2017
The preventive effect of the bounding exercise programme on hamstring Injuries in male amateur soccer players. Dutch Sports Medicine Society annual congress, Ermelo	2017
The hamstring Outcome Score as predictor for safe Return to play? Physical Therapy Science, Utrecht	2017

Other podium presentations

Clinical Health Scientist …. And now? “Meet the expert”, Physical Therapy Sciences, Utrecht University — 2016

Hamstring injury prevention and return to play. Dutch society of physical therapy in sports health. Regional meeting, Den Haag. — 2017

The preventive effect the Bounding Exercise Program on hamstring injury incidence in male amateur soccer players. Symposium ZonMW projects from University Medical Center Utrecht, the Royal Netherlands Football Association, Zeist. — 2018

Teaching

Teaching and coordinating (since 2017) the trajectory Academic skills and Reasoning year 1, BSc SOMT University of physiotherapy, Amersfoort. — 2016-2020

Supervision

De Jong E, The hamstring outcome score and risk for hamstring injury in Dutch amateur soccer players. Academic Assignment, Master Sport Science, University of Groningen, University Medical Center Groningen. — 2017

Nevels R. Return to play characteristics that could indicate increased risk for recurrent hamstring injury. Academic Assignment, Master Sport Science, University of Groningen, University Medical Center Groningen. — 2017

Brauers JJ. The effect of lower extremity plyometric training on performance outcomes in adult male football players: A systematic review. Systematic Review, Master Clinical Health Sciences – Physical Therapy Sciences, Utrecht University. — 2017

Nevels R. Neuromuscular Adaptations of Plyometric Exercise in Team Sports: A systematic Review. Review, Master Sport Science, University of Groningen, University Medical Center Groningen. — 2017

Hendriks S. The hamstring outcome score as decision making tool in Return to play. Academic Assignment, Master Sport Science, University of Groningen, University Medical Center Groningen. 2018

Meijdam J. Reasons (not) to comply to injury prevention in Dutch amateur soccer. Academic Assignment, Master Sport Science, University of Groningen, University Medical Center Groningen. 2018

List of Publications

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

Van de Hoef S, Huisstede BMA, Brink MS, de Vries N, Goedhart EA, Backx FJG. The preventive effect of the Bounding Exercise Programme on hamstring injuries in amateur soccer players: The design of a randomized controlled trial. BMC Musculoskelet Disord. 2017 Aug 22;18(1):355.

Van der Horst N, van de Hoef S, van Otterloo P, Klein M, Brink MS, Backx FJG. Nordic Hamstring Exercise is Effective but not adopted. Understanding why evidence based hamstring injury prevention is not adopted in football. *Clin J of Sport Med*. 2018 Dec 13.

Van de Hoef PA, Brink MS, Huisstede BMA, van Smeden M, de Vries N, Goedhart EA, Gouttebarge V, Backx FJG. The preventive effect of the bounding exercise programme on hamstring injuries in amateur soccer players. Scand J Med Sci Sports. 2019 Apr;29(4):515-523

Van de Hoef PA, Brauers JJ, Backx FJG, Brink MS (2018). The effects of lower-extremity plyometric training on soccer specific outcomes: a systematic review and meta-analysis. Int J Sports Physiol Perform. 2019 Dec 4:1-15.

Van de Hoef PA, Brink MS, van der Horst N, van Smeden M, Backx FJG. The prognostic value of the Hamstring Outcome Score to predict the risk of hamstring injuries. Submitted

Van de Hoef PA, Brink MS, Brauers JJ, van Smeden M, Gouttebarge V, Backx FJG. Players' age, experience and perceptions affect adherence to an injury prevention program in male amateur football. Submitted

Brauers JJ, van de Hoef PA, van Smeden, Backx FJG, Brink MS. Are off-field activities a risky business for hamstring injuries in male amateur football? A prospective cohort study. Submitted

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Awards

Communicator Award, Clinical Health Sciences, Utrecht University, 2015

Vyaire price for 'Best scientific article', Dutch Sports Medicine Society annual congress, Ermelo, 2019

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