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Multifactorial individualised programme for hamstring muscle injury risk reduction in professional football: protocol for a prospective cohort study

Johan Lahti [ID],[1] Jurdan Mendiguchia,[2] Juha Ahtiainen,[3] Luis Anula,[4] Tuomas Kononen,[5] Mikko Kujala,[6] Anton Matinlauri,[7] Ville Peltonen,[8] Max Thibault,[9] Risto-Matti Toivonen,[10] Pascal Edouard,[11,12] Jean Benoit Morin[1,13]

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For numbered affiliations see end of article.

Correspondence to
Johan Lahti, Université Cote d'Azur, LAMHESS, 261 Bd Du Mercantour, Nice, France; lahti.johan87@gmail.com

ABSTRACT

Introduction Hamstring muscle injuries (HMI) continue to plague professional football. Several scientific publications have encouraged a multifactorial approach; however, no multifactorial HMI risk reduction studies have been conducted in professional football. Furthermore, individualisation of HMI management programmes has only been researched in a rehabilitation setting. Therefore, this study aims to determine if a *specific* multifactorial and individualised programme can reduce HMI occurrence in professional football.

Methods and analysis We conducted a prospective cohort study over two seasons within the Finnish Premier League and compare the amount of HMI sustained during a control season to an intervention season. Injury data and sport exposure were collected during the two seasons (2019–2020), and a multifactorial and individualised HMI risk reduction programme will be implemented during intervention season (2020). After a hamstring screening protocol is completed, individual training will be defined for each player within several categories: lumbo-pelvic control, range of motion, posterior chain strength, sprint mechanical output and an additional non-individualised 'training for all players' category. Screening and respective updates to training programmes were conducted three times during the season. The outcome will be to compare if there is a significant effect of the intervention on the HMI occurrence using Cox regression analysis.

Ethics and dissemination Approval for the injury and sport exposure data collection was obtained by the Saint-Etienne University Hospital Ethics Committee (request number: IORG0007394; record number IRBN322016/CHUSTE). Approval for the intervention season was obtained from the Central Finland healthcare District (request and record number: U6/2019).

INTRODUCTION

In professional football, hamstring muscle injuries (HMI) account for 20–26% of all sustained injuries,[1 2] making them one of the most prevalent. Furthermore, nearly one-third of HMI have been reported to recur.[3] HMI has been considered a long-lasting, unresolved problem within football[4]; according to some research, HMI have increased.[5] Due to lost playing and training time, HMI is considered being one of the largest burdens in professional football, including diminished performance and financial loss.[2 5] Therefore, there is a need to continue improving HMI risk reduction strategies.

HMI are most often sustained during sprinting, but also commonly via slide tackling (overstretch), cutting (change of direction) and kicking.[1] Multiple intrinsic risk factors have been established with large variation in importance, some of which are unmodifiable, including age, gender, ethnicity and injury history.[4 6] Possible modifiable intrinsic risk factors include the strength of the hamstring and surrounding lumbo-pelvic muscles, strength asymmetry, fatigue tolerance, muscle architecture, range of motion (ROM), lack or excess of high-speed sprinting and sprint performance technique.[4 7] Therefore, by present-day standards, the underlying optimal strategy to manage HMI is generally agreed to be multifactorial.[4 7 8] Furthermore, these training strategies should be contextualised to the general demands of the sport and changes within practice. Practitioners and scientists contest the extent to which each intrinsic risk factor can be modified and how each of them should be trained.[4 7–10] Multiple intervention programmes within football have aimed to reduce the risk of HMI by unifactorial means, with both the largest focus and success given to isolating improvements in eccentric knee flexor strength.[11–13] However, to the best of our knowledge, no multifactorial injury reduction studies have been conducted in professional football settings where the demands are arguably the highest.

Additionally, there are no unifactorial or multifactorial HMI risk reduction studies using high-speed sprinting as a training method. This is despite evidence showing that the potential lack of optimal sprinting kinematics,[14 15] a lack of exposure to maximal velocity sprinting[16] and even lower sprint performance[17] are risk factors associated with lower body and HMI in sprint-based team sports. The inclusion of sprint work is further made compelling by the fact that sprint performance capability is considered one of the key performance tests distinguishing lower- and higher-level football athletes.[18 19] The muscle activity of the hamstrings in sprinting surpasses common hamstring strengthening exercises,[20] which supports their use as a time-efficient means of training for performance and injury risk reduction simultaneously. This in return could foster cooperation between team physiotherapists and strength and conditioning coaches, which might help create a multidisciplinary practical approach for reducing the risk of HMI.

Although a general multifactorial injury risk reduction approach is likely needed, professional football players vary substantially in how many risk factors they possess.[3] Therefore, from a holistic injury management perspective, a multifactorial approach should be individualised.[4 7 21] Specifically, individualisation is an approach where training towards a certain common outcome, such as reducing injury occurrence (eg, injury risk reduction programmes), is constructed to a certain extent independently for every player. This is done by first evaluating what training stimuli a certain individual seems to require based on categories of 'screening' tests. Research within football using individualised training for HMI risk reduction has only been completed once,[22] whereas research including individualised multifactorial training has only been performed within a hamstring rehabilitation setting.[21] Individualisation can also be done by merely manipulating the training volume of a certain stimuli or even within exercise selection depending on the situation.[23]

Therefore, this study aims to determine if a *specific* multifactorial and individualised programme can reduce the occurrence of HMI in a professional football setting.

METHODS AND ANALYSIS

Study design and procedure

We conducted a prospective cohort study over two professional football seasons. The 2019 season serves as the control season, including sport exposure and injury data collection. The 2020 season serves as the intervention season, including the implementation of a multifactorial and individualised HMI risk reduction programme in addition to the sport exposure and injury data measurements obtained, as per the control season. The study design is presented in figure 1.

Participants

The participants were recruited from teams within 'Veikkausliiga', the professional football premier league in Finland. For each team, the recruitment will be done by separately contacting each team's strength and conditioning coach and physiotherapist. The teams within the league without a full-time strength and conditioning coach and a physiotherapist are included in the present study. Thereafter, the objectives, procedure and risks of the study are explained orally and in written format by the leading author (JL) to the staff and players. Strong contact networks have already been established with all the participating teams due to an ongoing collaborative research projects within the same league. Subsequently, players were included or excluded based on the criteria presented in table 1.

Written consent for the study will be sent via email at least 1 week prior to initial testing, and participants must have signed consent. Players under 18 require parental approval. Participation is entirely voluntary, and they may refuse any test or exercise at any time and for any reason. Participation, suspension or exclusion will in no way affect the position of those recruited for research in their team community.

Patient and public involvement

Many of the researchers (JL, JM, LA, TK, MK, AM, VP, MT and R-MT) involved in the present study have worked and continue to work in clinical practice dealing with injured football players. As they have shared their stories underpinning injury occurrence, these football players

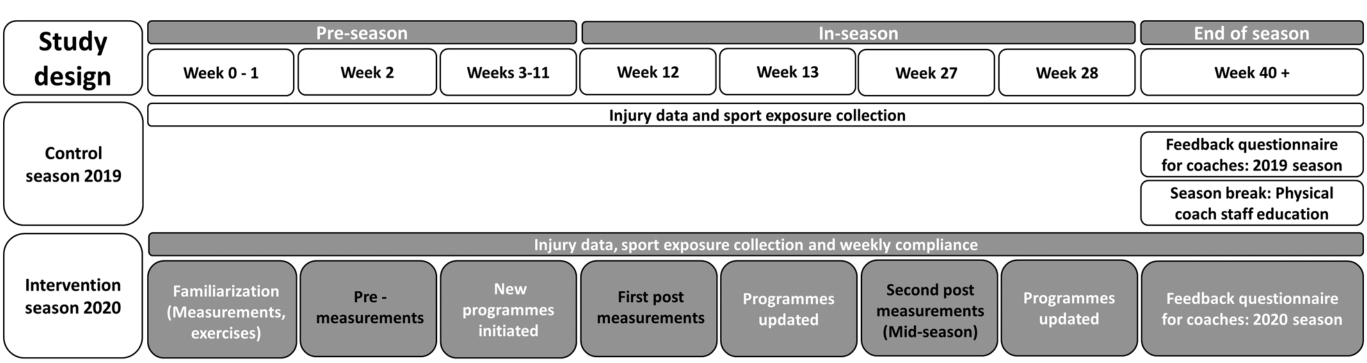


Figure 1 Study design. The study includes one control season (2019) and one intervention season (2020) with a total of three measurements.

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criterion
► The player accepts that their medical data can be collected ► The players are involved in training sessions through the start of the 2019 and 2020 preseason (January) to end of the season (October).	► Goalkeepers (only field players included due to a higher hamstring injury risk).

indirectly assisted in the hypothesis-making process for the current study. No football players were, however, invited to take active part in the design of the current study via, for example, knowledge-transfer scheme.

Primary outcome: HMI

Injury definition and data collection

Injury is defined as traumatic or overuse physical damage that occurred during a scheduled training session or match that caused absence from the next training session or match.[24] Injury data are prospectively collected and registered by each team's physiotherapist, using a standardised report form including the date of injury, circumstances (match/training), injury location, type, cause and date of return to play.

Hamstring muscle injury definition

The primary outcome of the present study will be the occurrence of HMI. HMI is defined as an injury, located at the posterior side of the thigh, and involving muscle tissue. Hamstring injuries defined as cramping/spasm are also included as muscle injuries. The diagnosis will be made by interview and physical examination of the players and confirmed by ultrasound or MRI.

Other data collection

Anthropomorphological measurements and player information

The players' body mass (in kg), height (in cm), age (in years) and player position are registered at the start of each of the two seasons. Further, the moment arm distances are measured at the knee and hip during manual dynamometry strength testing so that strength can be reported in torque format.

Sport exposure definition and data collection

Sport exposure is defined as weekly training hours and matches within each team's season. This data will be collected by either the team strength and conditioning coach or physiotherapist.

Physical coach staff education

After measurements, full responsibility will be given to each team's physiotherapist and strength and conditioning staff to instruct and monitor the completion of the training programme. To ensure high standards, video material and a weekend workshop were organised for all strength and conditioning coaches, physiotherapists and other practitioners responsible for injury risk reduction within the team.

All staff participating in the educational workshop and subsequent data collections complete two questionnaires at different time points during the study to improve the qualitative interpretation of results (online supplemental tables 8 and 9). The first questionnaire, completed at end of the 2019 season but before the educational workshop, aims to clarify understanding of current HMI risk reduction practices within the team. The second questionnaire, completed before the end of the intervention season, aims to determine what training categories and methods of the intervention the participating staff consider to be the most impactful on their practice compared to the control season. It includes their opinion on the compliance of the players. Furthermore, the lead author (JL) of the study will be fully available for questions during the entire study.

Intervention: multifactorial and individualised HMI risk reduction programme for professional football

Each player's HMI injury risk reduction *training protocol* will be largely based on the results of the multifactorial hamstring *screening protocol* results, which determines individualised training targets. The implementation of the entire injury risk reduction training protocol will be managed by the team's strength and conditioning coach and physiotherapist after being fully educated at the end of the control season.

Overview of the hamstring screening protocol for football (Football Hamstring Screening)

The intervention season includes three sessions of screening tests over the ~42-week season (figure 1). For each team, all screening tests were performed within a 2-day period and completed once at the start of pre-season (PRE), once at the end of the pre-season or start of the season (POST1) and a final test mid-season (POST2). Due to different scheduling of team practices, teams were screened within 3 weeks of each other.

The Football Hamstring Screening (FHS) protocol will be divided into the following categories that we considered important for football players: lumbo-pelvic control, ROM, strength and sprint mechanical output (figure 2). All clinical tests included in the lumbo-pelvic control, ROM and strength assessment total of 20 min per player. The sprint mechanical output test, which will be combined with sprint kinematic 'kick-back' analysis for the lumbo-pelvic control screening category, lasts 3–5 min per athlete or 10–15 min for the entire team. To improve reliability, all tests within each team were performed by the same experienced clinician (JL) with a mandatory familiarisation for all clinical screening tests 1 week pre-testing. Appropriate initial steps are taken to help transfer the screening protocol into practice. Reliability testing has been conducted (manuscript in revision) in combination with a prospective cohort study to help support the FHS protocols validation in accordance with Bahr *et al*.[25]

Efforts are made to standardise the order and timing in which teams and players are screened and the given exposure time to the training intervention before post screenings are initiated. The FHS protocol is divided into clinical tests and sprint tests, both of which are tested before practice and/or on a rest day. To control for fatigue, players completed clinical testing a minimum of 72 hours post matches,[26] whereas sprint testing will be completed a minimum of 96 hours post matches.[27]

This research project will be specifically designed so that both the screening and training protocols can be efficiently integrated into the athletes' training environment. This will be possible as the teams already have reserved time slots for their own frequent testing and physical training protocols, and the changes made by the research protocol were made in their own training environment and support the general aims of their practice.

Lumbo-pelvic control tests

Lumbo-pelvic control will be tested via one clinical test and one sprint kinematics test done in parallel with sprint mechanical output testing. The first lumbo-pelvic control test, that is a part of the clinical tests, is named the 'walk test', which uses a validated WIVA digital gyroscope (Let-Sense Group, Castel Maggiore, Italy) to estimate 3D pelvic kinematics in walking.[28] It has greater intrasubject and intersubject repeatability for pelvic kinematics measurements compared with stereo optoelectronic systems.[29] To further improve reliability, we use a composite score of the sagittal and frontal plane pelvic movement in normal gait. The test includes the player walking 10 m forward and back twice with the WIVA digital gyroscope attached to the S1/L5 junction.

The second lumbo-pelvic control test will be included in the 30 m maximal sprint performance test, which assessed simple sagittal plane 2D upright sprinting kinematics using a high-speed camera (240 fps) at the 22.5 m mark, 11 m perpendicular to the line of sprinting. This test aims to indirectly assess suboptimal sagittal plane lumbo-pelvic movement in sprinting by focusing on the lower-limb angles at touchdown and toe-off (figure 3). Excess rotational work being completed by the lower limbs 'behind the body' (centre of

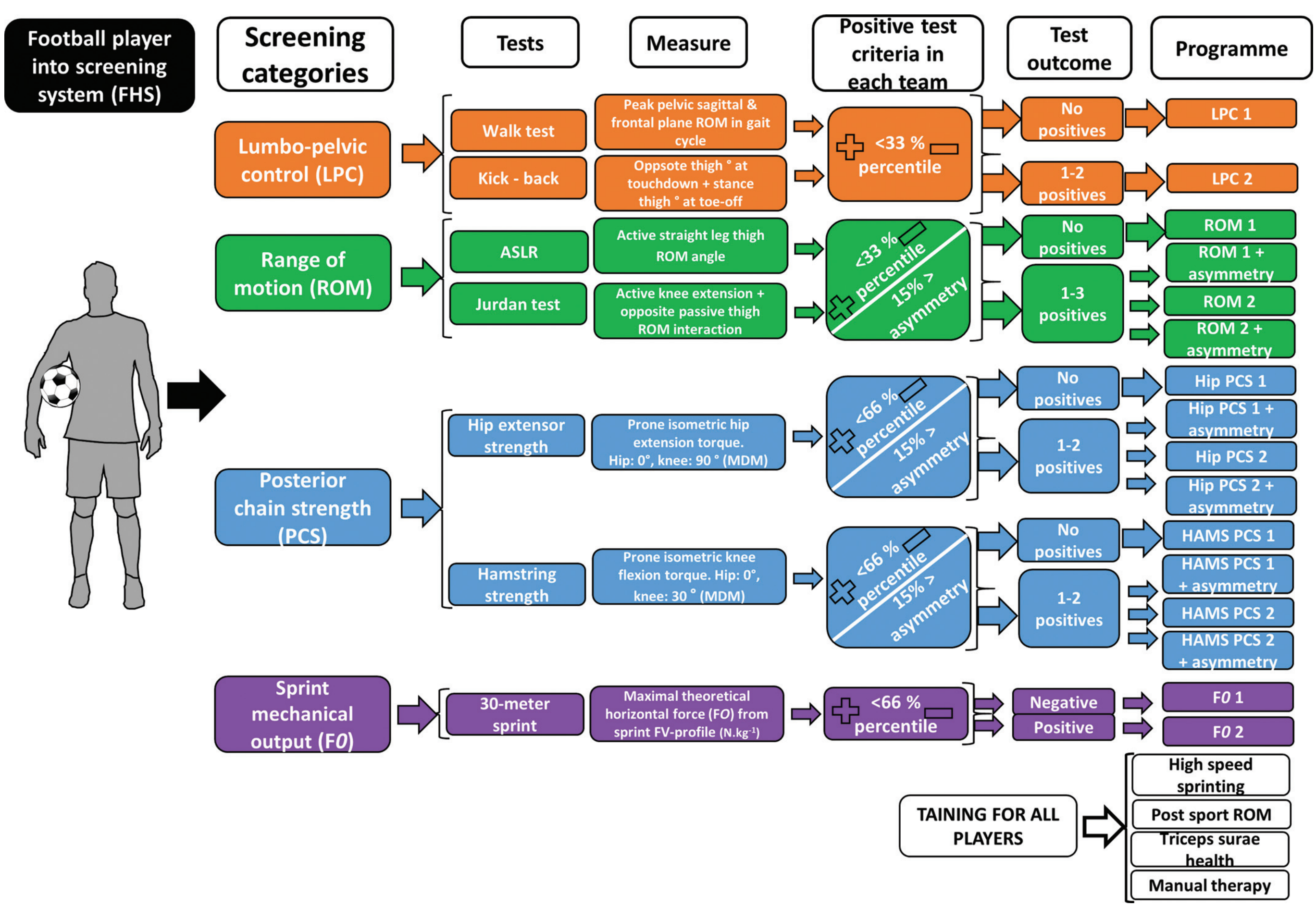


Figure 2 Hamstring screening protocol and training programme selection. Initially, the football player is tested within four screening categories. A percentile method within each team is used in all categories to define whether a player's test outcome is positive or negative. Further, asymmetry is measured in the ROM and strength screening categories, adding further detail to the programmes. ASLR, Active Straight Leg Raise; FHS, Football Hamstring Screening; MDM, manual dynamometer.

mass) is associated with the 'kick-back' mechanism and is a sprint coach concept related to the quality of 'front-side mechanics'.[30] Angles are calculated based on the mean value of two strides (touchdown and toe-off) within two maximal sprints using Kinovea video analysis software (v.0.8.15), and an example of the calculation method is provided in figure 3.

ROM tests

The FHS protocol includes two ROM tests: Active Straight Leg Raise (ASLR) and a new proposed test named the 'Jurdan test' (figure 4C and D). After one familiarisation repetition, tests are performed twice at a slow pace (3 s), and angles averaged for improved reliability using a validated digital goniometer app (Goniometer Records, Indian Orthopedic Research Group).[31]

The ASLR test has been shown to be a high reliability active hamstring flexibility test, where the thigh angle is measured from a controlled straight leg lift in supine position.[32] The Jurdan test is new to the literature and is derived from anecdotal observations by experienced health professionals to be an interesting option for further scientific scrutiny. The aim of the test is to demonstrate the interaction between hip flexor and hamstring flexibility, which has been considered a potential risk factor in sprinting.[33] The Jurdan test position and execution is considered to be a combination of the modified Thomas test[34] and the active knee extension test.[32] Initially, the participant is supine in a similar position to the modified Thomas test but is asked to complete an active knee extension (holding the thigh at 90°) while holding the table and holding the lumbar spine in contact with the table. The lumbar position will be verified kinaesthetically by the practitioner in the starting position and visually during execution. Maintenance of the thigh angle at around 90° for the active knee extension during testing is visually verified. The result will be defined as the difference between the actively lengthened legs shin angle and the opposite legs passive thigh angle (which is hanging over the table's edge). Both angles are measured relative to horizontal. From figure 4C and D, this corresponds to the following calculation: 53°—(−16°)=69°, where 53° is the shin angle and −16° is the opposite leg's negative thigh angle. Another example result that leads to the same value, but different ROM values would be 72°–(3°)=69°, where 72° is the shin angle and 3° is the opposite leg's positive thigh angle. Therefore, this composite angle does not focus on which specific leg's ROM is potentially the most problematic but instead focuses more on the leg interaction. This also corresponds to the approach behind the selected risk reduction ROM exercises in the training programme.

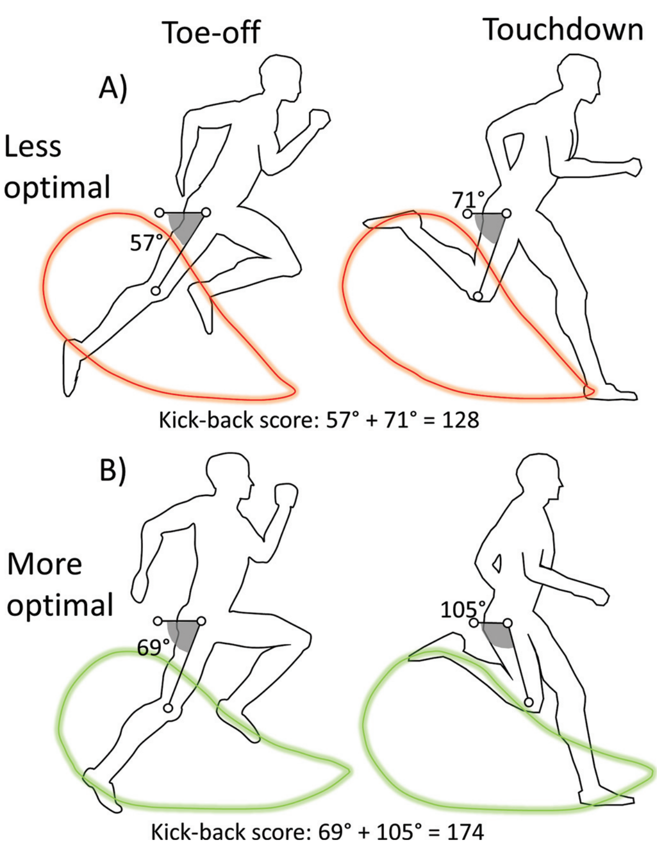


Figure 3 The 'kick-back' mechanism is quantified by composite angle score within the sprint stride; the contralateral thigh angle at touchdown and the ipsilateral thigh angle at toe-off. Angles were placed after first manually digitizing of the hip, and knee joint centres. Less (A) or more optimal (B) is based on both anecdotal evidence from practitioners and Schuermans *et al*[14] results (see figure 4 for a similar visual). The less or more optimal movement is also visualised with tracking the foots path through the sprint stride cycle. Within each team, football players' kick-back mechanism will be classified as positive if they are ranked at or under the team's percentile of 33%, corresponding to increased lumbo-pelvic training.

Posterior chain strength tests

Isometric strength for hip extensors and knee flexors will be assessed using a handheld dynamometry method in previously described reliable positions.[35 36] Participants laid in a prone position on a table while strapped from the waist (figure 5). The knee flexors are tested in 0° of hip extension and 30° of knee flexion with force placed on the heel. The knee flexion angle start position will be verified by the digital goniometer. As no apparatus will be used to hold the knee flexion position during contraction, shielding during contraction is expected to be around 5°. The hip extensors are tested in a 0-degree position with the knee extended to 95–100° with force placed on the distal tibia. The dynamometer will be placed at ~5 cm from knee flexion crease,[33] which determines how far the shin needs to be pushed backed so that the calf muscle is not in the way. A belt will be placed across the hips to avoid raising of the gluteals during the test.

Sprint mechanical output test

Players perform two 30 m maximal sprints in sequence with football practice. Specifically, sprints are performed

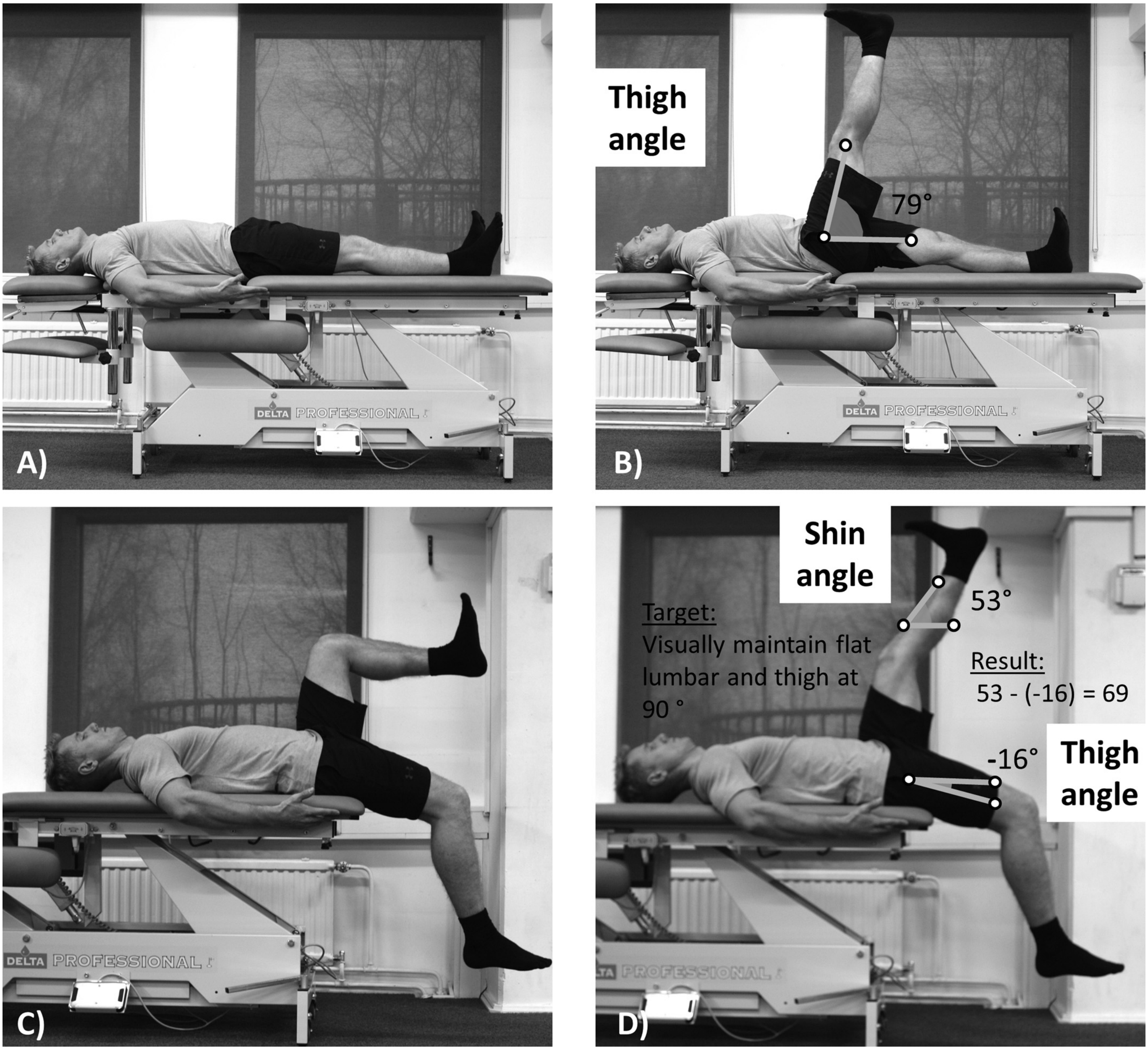


Figure 4 Range of motion tests used in the study. Picture (A) and (B) are from the Active Straight Leg Raise test (ASLR) and pictures (C) and (D) from the 'Jurdan test'. Within each team, football players' range of motion will be classified as positive if they are ranked at or under the team's percentile of 33% in any of the range of motion tests, corresponding to increased range of motion training. If asymmetry is found between legs (≥15%), increased range of motion training will be prescribed for the less flexible leg.

after the team's normal sprint testing warm-up protocol and with 3 min of passive recovery between sprints. Sprint performance (split times 0–5, 0–10, 0–20 and 0–30 m), maximal velocity and sprint mechanical output (ie, maximal theoretical horizontal force (F0)) are computed using a validated field method measured with a radar device (Stalker ATS Pro II, Applied Concepts, TX, USA) as reported previously.[37–39] Briefly, this computation method for F0 is based on a macroscopic inverse dynamic's analysis of the centre-of-mass motion. Raw velocity–time data wereare fitted by an exponential function. Instantaneous velocity data are then be combined with system mass (body mass) and aerodynamic friction to compute the net horizontal antero-posterior ground reaction force.[39] Individual linear sprint force–velocity profiles are then extrapolated to calculate relative F0.

Individualised HMI risk reduction protocol

Training within the HMI risk reduction protocol will be completed in the exact same categories as used within the FHS protocol: lumbo-pelvic control (table 2), ROM (table 3), posterior chain strength (table 4) and sprint

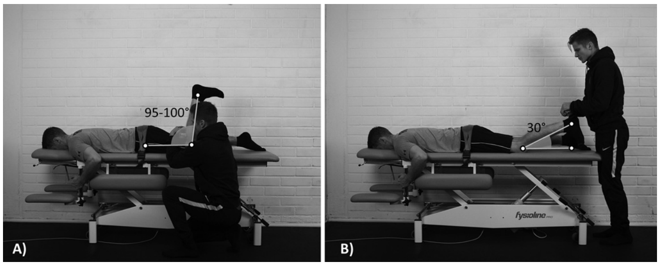


Figure 5 Posterior chain strength tests. The hip extensors are tested in position (A) and knee flexors in position (B). Within each team, football players' knee flexor strength and hip extensor strength are separately classified as positive if they are ranked at or under the team's percentile of 66%, corresponding to increased strength training for the respective joint. If asymmetry is found between legs at any joint (≥15%), increased training is prescribed for the weaker leg.

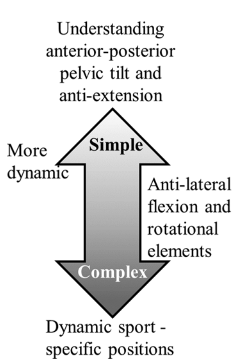
mechanical output (table 5). In every screening test category, football players are either ranked as positive or negative within each team and then accordingly given individual training protocols that are instructed by each team's coaching staff (figures 2 and 6). The approach for determining positive and negative cut-offs is explained in more detail in the following section. Each individualised training protocol includes the same exercises for all players, but the training volume varied based on the individual. In practical terms, if a weakness is found (ie, 'positive' result), the player should work on the weakness more. However, due to the physical requirements in football, even those with negative test scores complete maintenance training within each category; therefore, all players benefit from at least minimal lumbo-pelvic, posterior chain strength, ROM and sprint mechanical output training.

Cut-offs used for individualisation of the HMI risk reduction protocol

Individual training protocols are designed largely based on a percentile cut-offs within each team in all four screening categories. These percentiles are based on both evidence-based guidelines and consistent anecdotal evidence from experienced practitioners within professional football in the research team. Current evidence suggests that strength training has the highest validity in injury risk reduction.[10] This is why the posterior chain strength category includes the highest cut-off percentile to classify positive or negative players compared to the other categories. This means that there is a higher likelihood that a player will be ranked as positive in the posterior strength training category compared to ROM and lumbo-pelvic control, leading to an increased training volume. Specifically, the higher percentile of 66% has been chosen for posterior chain strength, whereas ROM and lumbo-pelvic control have a lower cut-off percentile of 33% (figure 6).

In practical terms, based on the screening scores in the lumbo-pelvic and ROM categories, a positive result (percentile ≤33%) corresponds to a target training volume of four times per week and a negative result (percentile >33%) corresponds to a target volume of twice per week. If there is more than one positive in a specific testing category, it has

Table 2 Lumbo-pelvic control



Structure of exercises within both A and B sessions	Exercise category	Weekly session volume (2–4 sessions)	Exercises	Sets and reps
	A	Negative test results: once per week (A) Positive test results: twice per week (A+A)	1. Stir the pot 2. Plank to bridge 3. Hip hinge 4. Anti-side flexion split squat jumps 5. Overhead A-skips	2×6 rotations per side 2×3 s holds per position 2×8 2×8 2×6–8 skips per side
	B	Negative test results: once per week (B) Positive test results: twice per week (B+ B)	1. Dead bug scissor kicks 2. Side plank roll to dead bug 3. Rotations with bar 4. Hip hinge into wall kick 5. Lateral overhead step-ups	2×8 kicks per side 2×3 s per position 2×5 m (forward and backward) 2×4 per side 2×4–6 per side

Programming design for lumbo-pelvic control. There are two categories of exercises (A and B) that follow the same simple-to-complex exercise structure either two or four times per week depending on the players test results. All exercises aim to have the player place the pelvis in a posterior pelvic tilt no matter from which direction the stability challenge is coming from. All exercises have been done in a circuit training format, with a 30 s break between exercises, repeated twice. As player boredom is likely an issue during the season, an updated exercise package is provided at the end of preseason.

Table 3 Range of motion (ROM)

Exercise category	Weekly session volume (two to four sessions)	Exercises	Sets and reps
Foam rolling	Rolling exercises are not mandatory and are advised to be completed if manual therapy is not received for the week.	1. Lower lumbar rolling 2. Latissimus rolling 3. Hamstring rolling 4. Adductor rolling	1×20 s in 3 regions 10 rolls per side 1×60 s 1×60 s per side
A	Negative test results: twice per week (A+A) Positive test results: four times per week (A+A+A+A)	1. Knee to chest 2. Hip flexor and hamstring slide 3. Hamstring hip flexor stretch in supine position 4. Dynamic hamstring leg raise 5. Hamstring neural flossing	1×20 2×8 per side 2×8 per side 2×8 per side 1×25

Programming design for ROM. The ROM exercises mostly focus on the hip flexor–hamstring ROM interaction and neural flossing of the sciatic nerve. However, the lumbar area has also been taken into consideration. Players complete all sets for a specific exercise with a 20 s break between sets, then transition to the next.

no further influence on the training protocol, with an exception made for the categories that include limb asymmetry measurements. Limb asymmetry will be measured in the ROM and strength categories, defined as a 15% difference between sides.[22] If an asymmetry is found within the ROM category, an extra set for all ROM exercises will be placed for the stiffer leg four times per week. If an asymmetry is found within the posterior strength category (hip extensor and/or knee flexor), an extra set within one exercise is required for the weaker leg once per week.

In the posterior chain strength category, a positive result (percentile ≤66%) corresponds to a target training volume of twice per week and a negative result (percentile >66%) corresponds to a target volume of once per week. The sprint mechanical output training category has the same percentile as the strength training category. In this case, both upper and lower horizontal force output players have the same training frequency, but the lower 66% has heavier resistance for early acceleration work, while the upper percentile predominantly works with lighter resistance. This is based on our research group's data currently in review, showing that players with elevated F0 output will likely respond less, or even not respond, to heavy loading.

Figure 6 provides more detailed aims for each training protocol category and how the test outcome, either positive or negative, determines the corresponding individualised weekly training session frequency (volume).

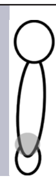
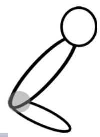
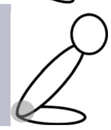
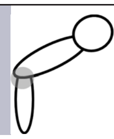
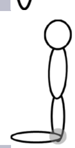
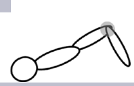
Non-individualised part of training within the intervention protocol

As briefly explained in figure 6 in the training category of 'Training for all players', as a research limitation, we found that some training stimuli will be impractical to provide on an individualised level versus a group level. These training subcategories include high-speed sprinting, post-sport ROM, triceps surae health and manual therapy (table 6). High-speed sprinting has been selected due to its potential benefits on injury risk reduction,[16] and provides an opportunity to work on the athletes' sprint 'technique'. Furthermore, this possibly contributes to improved lumbo-pelvic control (publication from our group in progress). This will be performed via different drills (table 7) and tools such as wicket hurdles. Post-sport ROM aims to relax the hamstrings and the latissimus dorsi after practice. The hamstrings are relaxed via a proposed compliance stimulus to the muscle-tendon unit via a light long contraction in a stretched position,[40] in theory counteracting the high stiffness stimuli provided from football practice. The latissimus dorsi will be relaxed by completing 10 deep breaths in a stretch relax format, with the aim to counteract stiffening and a possible anterior pull on the pelvis.[41] The third subcategory will be triceps surae health. This subcategory has been chosen based on evidence suggesting ankle and hamstring injuries may be related in linear sprinting.[42] Neural adaptations are prioritised with isometric holds at short muscle length ankle positions that are specific to sprinting (initial contact and mid-stance angles).[43] This in turn may improve stiffness and support overall improvements in sprint performance and technique.[44] Longer muscle length isometric holds have been shown to stimulate structural adaptations[43] and longer isometric holds seem to contribute to overcoming tendon stress shielding caused by repetitive microtrauma.[40 45] Therefore, to support the players' seasonal triceps surae load tolerance, long isometric holds at longer muscle lengths are used. The fourth subcategory, manual therapy, aims to more precisely influence compliance of the hamstrings and muscle tissues, possibly affecting anterior pelvic tilt. Manual therapy will be performed ideally by the team physiotherapist to the adductor magnus, erector spinae, latissimus dorsi and hamstrings. If manual therapy treatment is not available within a specific week, it is replaced by foam rolling to the same tissues (table 3).

Programming guidelines and compliance

General advice is provided to all teams on the ideal placement of training categories during one match (figures 7) and two match weeks (figure 8). Exercises have been designed considering budget differences between teams

Table 4 Posterior chain strength

Hip	Area of focus		Exercises to choose from	Day 1 (A): sets and reps	Day 2 (A): sets and reps (if test result is positive)
1—Hip	Extended (0–60°)		Hip thrust/glute bridge (bil/uni), quadruped hip extension, back extension (bil/uni)	2–3×4–8 (6–10 RM)	2–3×4–8 (6–10 RM)
2—Hip	Mid—range (60–90°)		Trapbar/sumo/traditional deadlift, 45° hyper, high sled push, high step-up	2–3×4–8 (6–10 RM)	2–3×4–8 (6–10 RM)
3—Hip	Deep (90–110°)		Squat/split squat variations, Romanian deadlift, low step-up, low sled push	1–2×4–8 (6–10 RM)	1–2×4–8 (6–10 RM)
If hip asymmetry	Extended (0–60°)		One extra set of a unilateral exercise in the extended category*	1×4–6 (6–10 RM)	
Set volume				5–7 (+1 for asymmetry)	5–7
Hamstrings				**Day 1 (B)**	**Day 2 (B)**
1—Hamstring	Hip over knee movement		Drop lunge into Romanian deadlift, perturbation stretches, straight leg dynamic cable pulls	1–2×4–6 per side (8–12 RM)	1–2×4–6 per side (8–12 RM)
2—Hamstring	Knee over hip movement		Nordic hamstring exercise, unilateral sliders, standing band curl	1–2×4–6 per side (6–8 RM)	1–2×4–6 per side (high eccentric effort)
3—Hamstring	Stiffness at knee and hip		Tantrums/bench heel kick/heel drops in lunge position	1–2×4–5 per side (tantrums in s)	
If hamstring asymmetry			One extra set of unilateral sliders†		1×4–6 (6–10 RM)
Set volume				3–6	2–4 (+1 for asymmetry)

*Asymmetry training is in the extended range of motion category as it is tested in this range.
†Unilateral sliders are chosen to correct hamstring asymmetry as it's a high load unilateral hamstring exercise reaching peak force in a similar angle as the test. Asymmetry for the hip extensors and hamstrings are advised to train on separate days to avoid excess volume sessions. Coaches choose one exercise (based on preference) from each category once to twice per week depending on test results. If asymmetry is found, complete the described extra exercise once per week. Rest between sets: 2 min. Set volume is manipulated based on athlete exposure/fatigue. RM for the given day is an approximation based on how the athlete is feeling. Athletes are advised to leave two to three repetitions in reserve in all exercises and avoid any technical sign of fatigue in stiffness exercises.
RM, repetition maximum.

to reduce bias favouring higher programme completion rates in better funded teams. Teams are advised to complete the following: lumbo-pelvic control and ROM training as a pre-warm-up; strength training so that hip strength, hamstrings, and triceps surae health are trained in the same time slot; sprint mechanical output and high-speed sprinting in combination with the team warm-up; manual therapy on off-days; and post-sport ROM after the last session of the day. Based on our ongoing discussions with the teams, there are both similarities and inevitable differences in weekly programming of the training categories due to different team cultures. For example, some teams' physical coaching staff might not be provided sufficient time to complete the entire training programme. All

Table 5 Sprint programming

Phase	Weeks	Day 1 Early acceleration(15–20 min)	Day 2 High-speed sprinting (12.5–17.5 min)	Day 3 (20–25 min) High-speed sprinting	Early acceleration	Total sprint volume Early acceleration	High-speed sprinting
Preseason: initiation	Week 1–3	A. Sprint drills 5 min B. Light/heavy sled work ×5 to 10–15m C. 5 m sprints×4, last two are races	A. Sprint drills 5 min B. Wicket sprints×3 to 45 m, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 100%. Wicket distance: progressive	A. Sprint drills 5 min B. Wicket sprints×3 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 100%. Wicket distance: progressive. Contrast first two wicket runs with sled sprints, total sled distance 2×15 m		130 +20=150 m (130 m sled work, 20 m first steps work)	135 +135=270 m (70 m is 100% sprinting)
Preseason: increase upright sprintingvolume, add curved sprinting	Week 4	A. Sprint drills 5 min B. Light/heavy sled work ×5 to 10–15 m C. 5 m sprints×4, last two are races	A. Sprint drills 5 min B. Wicket sprints×4 to 45, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive. 90% runs are curved (1×left, 1×right).	A. Sprint drills 5 min B. Wicket sprints×4 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive 90% runs are curved (1×left, 1×right). Contrast first two wicket runs with sled sprints, total sled distance 2×15 m		130 +20=150 m (130 m sled work, 20 m first steps work)	180 +180=360 m (70 m is 100% sprinting)
Pre-season: Increase early acceleration sprinting volume	Week 5–7	A. Sprint drills 5 min B. Light/heavy sled work ×6 to 10–15m C. 5 m sprints ×4, last two are races	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance, progressive from 1.5 to >1.8 m. 90% runs are curved (1×left, 1×right).	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive. 90% runs are curved (1×left, 1×right). Contrast first wicket run with sled sprints, total sled distance 1×15 m		135 +20=155 m (160m sled work, 30m first steps work)	180 +180=360 m (70 m is 100% sprinting)
Taper: used before post-testing or double match weeks in-season	Week 8	A. Sprint drills 5 min B. Light/heavy sled work ×3 to 20 m C. 5-m sprints ×4, last two are races	A. Sprint drills 5 min B. Wicket sprints ×3 to 45 m,10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 100%. Wicket distance: progressive	REST		80 m (60m sled work, 20 m first steps work)	135 m (45 m is 100% sprinting)

Continued

Table 5 Continued

Phase	Weeks	Day 1	Day 2	Day 3 (20–25 min)		Total sprint volume	
		Early acceleration(15–20 min)	High-speed sprinting (12.5–17.5 min)	High-speed sprinting	Early acceleration	Early acceleration	High-speed sprinting
In-season: one match week structure	Same as week 5–7 structure	A. Sprint drills 5 min B. Light/heavy sled work ×6 to 10–15 -m C. 5 m sprints×4, last wo are races	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, 10 m rolling start before wickets, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance, progressive from 1.5 to >1.8 m. 90% runs are curved (1×left, 1×right).	A. Sprint drills 5 min B. Wicket sprints ×4 to 45 m, full acceleration start 10 m, 20 m wickets, 15 m run through. Intensity: 80%, 90%, 90%, 100%. Wicket distance: progressive. 90% runs are curved (1×left, 1×right). Contrast first wicket run with sled sprints, total sled distance 1×15 m		135 +20=155 m (160 m sled work, 30 m first steps work)	180 +180=360 m (70 m is 100% sprinting)

teams have already confirmed the entire staff would collaborate to provide the highest compliance possible, but the reality is portrayed in the compliance data.

Therefore, each week the coaching staff records all completed sessions for all players within each training component. Furthermore, in training within the high-speed sprinting subcategory, all sprints instructed to be at or over 90% are reported in metres. All the data are anonymously uploaded to a server every week for verification. From here, the compliance to the intervention training protocol is calculated each week: (completed intervention sessions/intervention training target)×100. This will be done in each training category so that compliance with specific training forms can be measured. A full report of team training schedules within a typical week is provided as online supplementary material once the study has been completed.

Sample size calculation

According to the literature, about 22% of the professional football players sustain a hamstring muscle injury during a season.[5] We believe that we can obtain a relative risk reduction of 66% by implementing the multifactorial and individualised programme, which has been shown to be realistic based on previous hamstring risk reduction literature showing up to 50–70% reductions.[11–13] This corresponds to obtaining a percentage of professional football players with a new hamstring muscle injury of around 7.5%. To attain a power of 80% (a=5%) we include 93 players per group, or 186 players in total. Estimating a dropout rate of 15%, 107 players are recruited per season, or 214 players in total. The number of participants necessary was calculated using the online UCSF Clinical & Translational Science Institute application (https://www.sample-size.net/sample-size-proportions/).

Statistical analysis

Descriptive analyses of the collected data (eg, player characteristics, screening test results, injuries, sport exposure) are first performed using frequency with percentages for categorical variables and mean with SD (±SD) for continuous variables. Descriptive statistics for the total number of HMI (and percentage of all injuries), duration of time lost from sport, HMI incidence (per 1000 hour of training, match and total football practice) and burden of HMI (number of days lost due to HMI per 1000 hour of training, match and total football practice) will be provided. Compliance with the training programme will be calculated.

To analyse the impact of the HMI risk reduction programme, we perform a Cox proportional hazards regression (or Cox regression) model using 'seasons' (ie, control season vs intervention season) as explanatory variables and the first occurrence of a 'new HMI' as outcome, adjusted for age, team, body mass, height and history of HMI (previous two seasons); the unit of analysis will be the individual player and time to first event will be analysed using cumulative hours of football practice (ie,

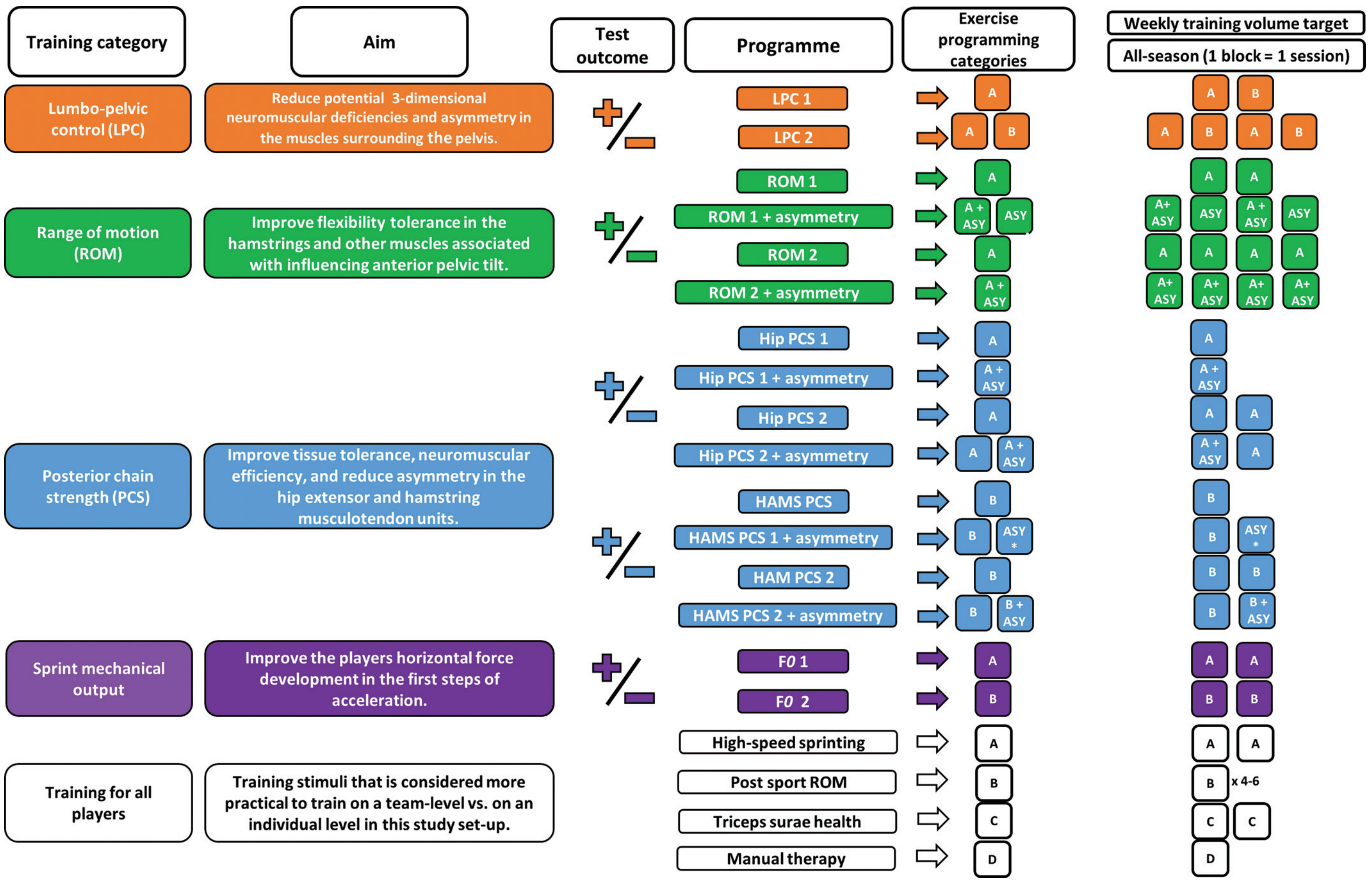


Figure 6 Brief rationale and programming methods of each training category during the entire season. In the last column, each square block represents one training session during the week. The number of blocks for every athlete are defined by the screening protocol outcomes. Target training volume is based on one match weeks. A full exercise list is provided in tables 2–7. *To avoid fatigue, hip and knee strength asymmetry are not tested within the same session.

Table 6 For all players exercises and treatments

Area of focus	Training volume (one match weeks)	Exercises
A. High-speed sprinting	Sprint drills: four times per week High-speed sprinting: twiceper week	Sprints drills and linear and curved sprinting with/without wickets. See tables 5 and 7 for programming.
B. Post-sport ROM	Once every training day and post match	Hamstrings: 30 s partner assisted very light isometric holds in the straight leg raise position Latissimus dorsi: 10 deep breaths in an overhead hanging position (TRX/rubber bands)
C. Triceps surae health	Twice per week	All done in rear elevated split position with barbell or without weight Set 1: High plantar flexion 1×10–30 s Set 2: 90° dorsiflexion 1×10–30 s Set 3:110° dorsiflexion 1×10–30 s
D. Manual therapy	Once per week	1. Erector spinae 2. Adductor magnus 3. Latissimus dorsi 4. Hamstrings

Table 7 Sprint drills programming

Week	Day	Exercises
Week 1–2	All 3 days	A-skip progressions, Pogo jumps (sagittal and lateral), dribble bleeds
Week 3–4	1	A-skip progressions, unilateral pogo jumps, dribble bleeds
	2	A-skip progressions, lateral A-skips
	3	Same as day 1
Week 5–6	1	A-skip progressions, lateral A-skips, scissors (high frequency)
	2	A-skip progressions, skip jumps, dribble bleeds
	3	Same as day 1
Week 7–8	1	A-skip progressions, lateral A-skips, scissors (progressive: high frequency to power)
	2	A-skip progressions, skip jumps, dribble bleeds, pogo jumps
	3	Same as day 1
In-season	1	A-skip progressions, lateral A-skips, scissors (progressive: high frequency to power to dribble bleeds)
	2	A-skip progressions, pogo jumps, skip jumps
	3	Same as day 1

training and competition) as a timescale. The HR with a 95% CI will be presented for each variable, and assumption that the HR will be constant over time will be tested.

Due to our main research question not being related to the changes in screening tests, we have not completed null hypothesis significance test statistics. However, to improve the relevance of discussions for clinicians, magnitude of difference statistics (effect size) will be performed for all screening categories between the three testing sessions.

ETHICS AND DISSEMINATION

This study has received two separate ethical approvals. The study protocol for the injury and sport exposure data collection used in the control season was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (Institutional Review Board: IORG0007394; IRBN322016/CHUSTE). This ethical approval was obtained in 2016 for conducting multicenter prospective injury data and sport exposure data collection but did not include the intervention. The study protocol for the intervention season was approved separately by the Central Finland healthcare District (U6/2019). Applying for one ethical approval that permitted for both prospective data collection from the 2019 control season followed by an intervention season was not possible, as the opportunity to conduct an intervention among professional football players was first provided in 2019, while prospective injury data and sport exposure data collection were in process. Thus, the ethical approval

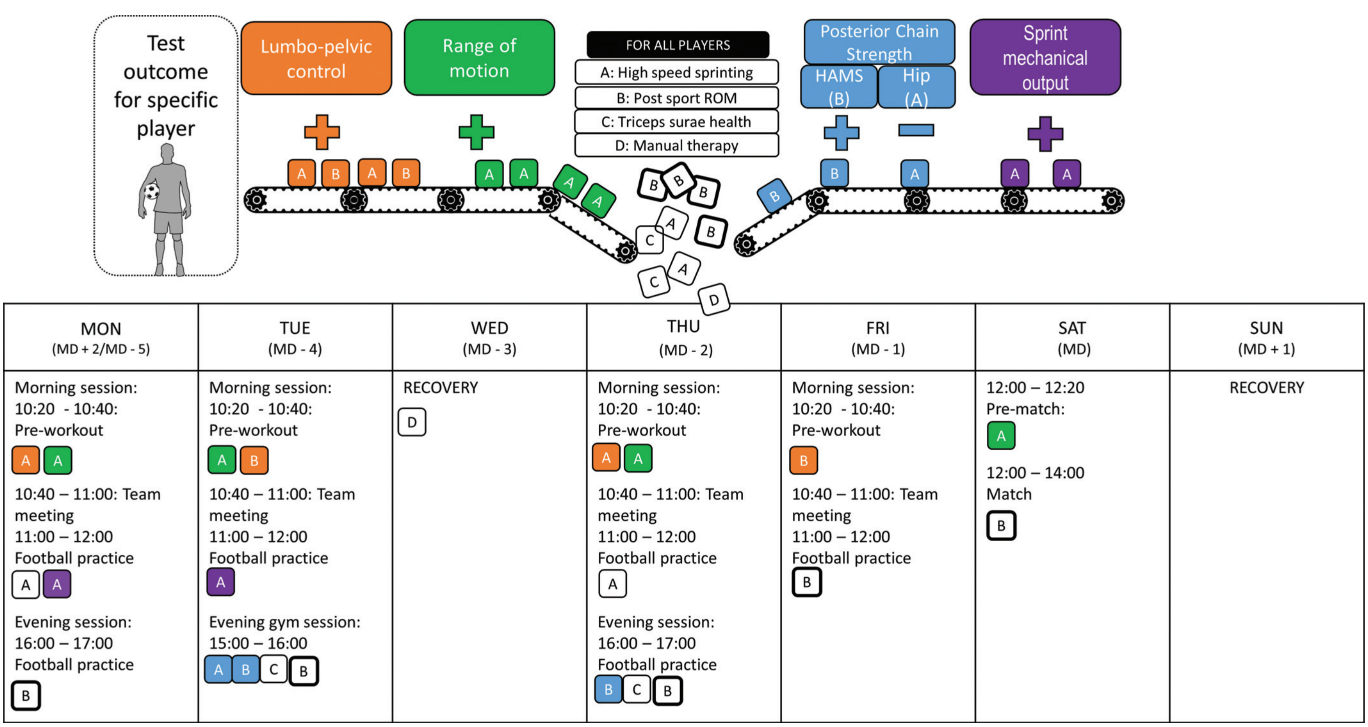


Figure 7 Example week for individualised and team programming for one match per week (on Saturday in this example). A hypothetical scenario is demonstrated based on one player's screening results. Each team finds slightly different solutions to fit in the training blocks, which are discussed in the main publication.

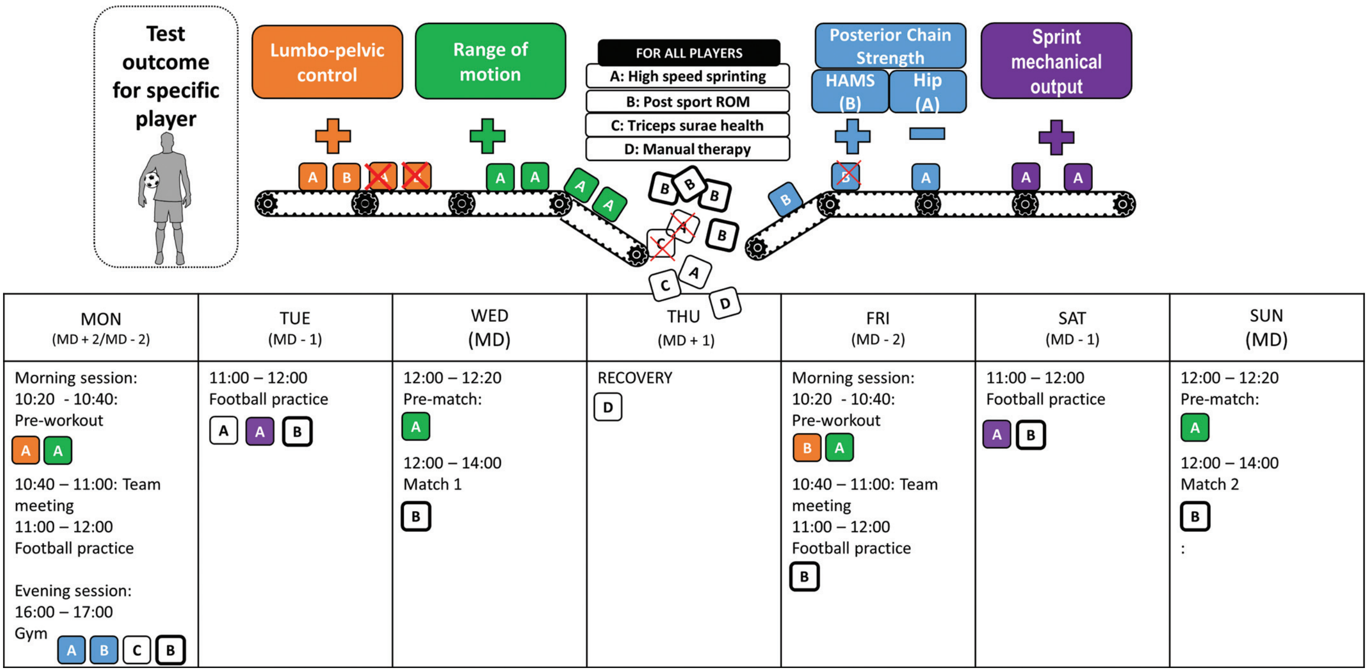


Figure 8 Example week for individuali'sed and team programming for two matches per week (Wednesday and Sunday in this example). On double match weeks, training sessions will be to different degrees sacrificed for improved recovery (red crosses).

for the intervention protocol was accepted at the end of the control season (2019). Therefore, our present study relies on two different ethical approvals: one for prospective data collection only corresponding to the first part of the study and the control season, and other for the intervention corresponding to the second part of the study and the intervention season. This study will be conducted in accordance with the Declaration of Helsinki.

Prior to enrolment in the study, all participants were asked to give their informed consent. The participants can decide at any time to be released from the study, and they are informed of this in the information documents. If accepted, data obtained during this study are used by the research team until their papers are accepted for publication, but for a maximum of 5 years, after which all materials will be destroyed. Participation is entirely voluntary, and participants may refuse any test or exercise at any time and for any reason. Participation, suspension or exclusion from this research study will in no way affect the position of recruits in their team community.

Results are published in a peer-reviewed sport and exercise medicine journal, regardless of the findings related to the number of positive or negative hamstring injuries sustained between the two seasons. In order to enhance knowledge translation of the findings, a multimodal approach will be used for dissemination; findings are presented at conferences, and multimedia resources (eg, infographics, animations, videos, podcasts and blogs) are created to share findings via various social media platforms and through media release.

CONCLUSIONS

Although there has been a large effort to include up to date evidence-based exercises for HMI risk reduction,[4 8 46] the aim of this study is not to answer what specific exercises (and their respective implementation strategies) are optimal. Our aim is to focus on the bigger picture and, thus, test the possible functionality of a specific multifactorial and individualised approach conceptualised for HMI risk in professional football.

There is consensus among sport scientists that multifactorial programming is necessary for hamstring injuries,[4 9–12] and we hope this study provides an interesting first step despite inevitable methodological limitations. Ideally, the teams are randomised to either a multifactorial programme or both multifactorial and individualised programme. However, this is difficult to create in real-life professional settings as many teams likely already have multifactorial and individualised protocols in use to varying extents. Thus, it is likely implausible in many cases that professional teams would agree to complete an intervention where their current protocols would be downgraded for the benefit of research. The format in which the screening protocol data is used to identify players at risk and assign individualised training protocols could be considered to be another limitation. Another approach would use non-linear machine learning algorithms based on data from multifactorial testing, emphasising the idea that no single data point is important in isolation.[47] These machine learning models are compatible with data that are considered important for most injuries in football, such as body mass, age, injury history, workload management and wellness scores.

Ideally, before conducting such an intervention, the screening protocol should be properly tested for its accuracy in identifying risk using such models with an entire control season devoted to it. In addition, since our aim is to maximise the dissemination and implementation of the intervention programme in the professional football community, we prefer using a relatively straightforward approach. This also provides an approach compatible with the data processing skills of most practitioners in real-life professional football. Therefore, we use the team percentile method, and future follow-up studies should analyse the interest of more advanced prediction models. If the protocol is successful, the current approach may work in other football populations with similar baseline values. However, it is inevitable that this approach presents its limitations in the form of producing false negatives and not being able to appropriately address players that are true positives. Additionally, updates and replacements to testing methods are encouraged within each testing category as advances in validated technology take place. Furthermore, it is important to state that this type of musculoskeletal multifactorial approach should ideally be a part of a biopsychosocial approach used for all injuries.[47] Finally, we acknowledge the fact that two separate ethical approvals were needed for one research project.

The strength of this study is its potential for direct practical implementation in teams with varying resources and budgets. We expect that reaching appropriate compliance is one of the greatest challenges facing this project. Most literature indicates that compliance is a clear problem in injury risk reduction protocols and likely explains the lack of results.[2 9 46 48] Player buy-in will be paramount, which itself will be mediated by the coaching practices within each team. We are optimistic that an injury risk reduction programme that considers the individual, both from a risk reduction and performance standpoint, might increase the potential for long-term compliance.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- This study helps to demonstrate the initial value of individualised training programmes based on a multifactorial hamstring screening protocol designed to reduce HMI in professional football.
- All testing and training are implemented in the field. Therefore, if the approach is successful in reducing HMI (study outcome), it has a high potential for direct transfer into practice. This includes free video links of all exercises once the study is completed.
- Normative data from the screening tests are published and provide a good initial reference database for practitioners looking to use the same tests.
- This study lacks randomisation and blinding, and therefore, at best provides good but not the highest level of evidence for validity of the HMI risk reduction programme.
- Comparing HMI between two separate seasons increases the risk of confounding factors affecting result interpretation.

Author affiliations
[1]LAMHESS, Universite Cote d'Azur, Nice, France
[2]Department of Physical Therapy, ZENTRUM Rehab and Performance Center, Barañain, Spain
[3]Faculty of Sport and Health Sciences, Neuromuscular Research Center, University of Jyvaskyla, Jyvaskyla, Finland
[4]KUPS, KUPS, Kuopio, Finland
[5]ROPS, ROPS, Rovaniemi, Finland
[6]SJK, SJK, Seinajoki, Finland
[7]HJK, HJK, Helsinki, Finland
[8]FC Inter, FC Inter, Turku, Finland
[9]FC Honka, FC Honka, Espoo, Finland
[10]HIFK, HIFK, Helsinki, Finland
[11]Sports Medicine Unit, Univ Hosp St Etienne, Saint-Etienne,France
[12]Inter-university Laboratory of Human Movement Science, Universite Jean Monnet Saint-Etienne,Saint-Etienne,France
[13]Sports Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, Auckland, New Zealand

Twitter Johan Lahti @lahti_johan.

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ORCID iD
Johan Lahti http://orcid.org/0000-0002-5406-7652

REFERENCES

1 Ekstrand J, Healy JC, Waldén M, *et al.* Hamstring muscle injuries in professional football: the correlation of MRI findings with return to play. *Br J Sports Med* 2012;46:112 LP–117.

2 Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and re-injury. *Sports Med* 2012;42:209–26.
3 Ribeiro-Alvares JB, Dornelles MP, Fritsch CG, *et al.* Prevalence of hamstring strain injury risk factors in professional and under-20 male football (soccer) players. *J Sport Rehabil* 2019;1–23.
4 Buckthorpe M, Wright S, Bruce-Low S, *et al.* Recommendations for hamstring injury prevention in elite football: translating research into practice. *Br J Sports Med* 2019;53:449–56.
5 Ekstrand J, Waldén M, Hägglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13- year longitudinal analysis of the UEFA elite club injury study. *Br J Sports Med* 2016;50:731.
6 Green B, Bourne MN, van Dyk N, *et al.* Recalibrating the risk of hamstring strain injury (HSI) - a 2020 systematic review and meta-analysis of risk factors for index and recurrent HSI in sport. *Br J Sports Med* 2020.
7 Mendiguchia J, Alentorn-Geli E, Brughelli M. Hamstring strain injuries: are we heading in the right direction? *Br J Sports Med* 2012;46:81–5.
8 Blandford L, McNeill W, Charvet I. Can we spread the risk? A demand-share perspective to sustained hamstring health. *J Bodyw Mov Ther* 2018;22:766–79.
9 Nassis GP, Brito J, Figueiredo P, *et al.* Injury prevention training in football: let's bring it to the real world. *Br J Sports Med* 2019;53:1328–9.
10 Shield AJ, Bourne MN. Hamstring injury prevention practices in elite sport: evidence for eccentric strength vs. *Lumbo-Pelvic Training Sport Med* 2018;48:513–24.
11 van der Horst N, Smits DW, Petersen J, *et al.* The preventive effect of the nordic hamstring exercise on hamstring injuries in amateur soccer players. *Am J Sports Med* 2015;43:1316–23.
12 Arnason A, Andersen TE, Holme I, *et al.* Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports* 2007;18:40–8.
13 Petersen J, Thorborg K, Nielsen MB, *et al.* Effect of eccentric training on acute hamstring injuries in men's soccer. *Am J Sports Med* 2011;39:2296–303.
14 Kenneally-Dabrowski C, Brown NAT, Warmenhoven J, *et al.* Late swing running mechanics influence hamstring injury susceptibility in elite rugby athletes: a prospective exploratory analysis. *J Biomech* 2019;92:112–19.
15 Schuermans J, Van TD, Palmans T, *et al.* Posture deviating running kinematics and hamstring injury susceptibility in male soccer players : cause or consequence ? *Gait Posture* 2017;57:270–7.
16 Malone S, Owen A, Mendes B, *et al.* High-speed running and sprinting as an injury risk factor in soccer: can well-developed physical qualities reduce the risk? *J Sci Med Sport* 2018;21:257–62.
17 Malone S, Hughes B, Doran DA, *et al.* Can the workload: injury relationship be moderated by improved strength, speed and repeated-sprint qualities? *J Sci Med Sport* 2018;22:29–34.
18 Cometti G, Maffiuletti NA, Pousson M, *et al.* Anaerobic power of elite, subelite and amateur French soccer players. *Int J Sports Med* 2001;22:45–51.
19 Devismes M, Aeles J, Philips J, *et al.* Sprint force-velocity profiles in soccer players: impact of sex and playing level. *Sport Biomech* 2019;1–11.
20 van den Tillaar R, Solheim JAB, Bencke J. Comparison of hamstring muscle activation during high-speed running and various hamstring strengthening exercises. *Int J Sports Phys Ther* 2017;12:718–27.
21 Mendiguchia J, Martinez-Ruiz E, Edouard P, *et al.* Criteria-based progressive algorithm for hamstring injury treatment. *Med Sci Sports Exerc* 2017;49:1482–92.
22 Croisier JL, Ganteaume S, Binet J, *et al.* Prevention of hamstring injury in professional soccer players. *Am J Sports Med* 2008;36:1469–75.
23 Jiménez-Reyes P, Samozino P, Morin JB. Optimized training for jumping performance using the force-velocity imbalance: individual adaptation kinetics (D Boullosa, Ed). *PLoS One* 2019;14:e0216681.
24 Waldén M, Hägglund M, Ekstrand J. Injuries in Swedish elite football - a prospective study on injury definitions, risk for injury and injury pattern during 2001. *Scand J Med Sci Sport* 2005;15:118–25.
25 Bahr R. Why screening tests to predict injury do not work-and probably never will: a critical review. *Br J Sports Med* 2016;50:776–80.
26 Matinlauri A, Alcaraz PE, Freitas TT, *et al.* A comparison of the isometric force fatigue-recovery profile in two posterior chain lower limb tests following simulated soccer competition. *PLoS One* 2019;14:e0206561.
27 Ispirlidis I, Fatouros IG, Jamurtas AZ, *et al.* Time-course of changes in inflammatory and performance responses following a soccer game. *Clin J Sport Med* 2008;18:423–31.
28 Bugane F, Benedetti MG, D'Angeli V, *et al.* Estimation of pelvis kinematics in level walking based on a single inertial sensor positioned close to the sacrum: validation on healthy subjects with stereophotogrammetric system. *Biomed Eng Online* 2014;13:146.
29 Bolink SAAN, Naisas H, Senden R, *et al.* Validity of an inertial measurement unit to assess pelvic orientation angles during gait, sit-stand transfers and step-up transfers: comparison with an optoelectronic motion capture system. *Med Eng Phys* 2016;38:225–31.
30 Haugen T, Danielsen J, Alnes LO, *et al.* On the importance of "front-side mechanics" in athletics sprinting. *Int J Sports Physiol Perform* 2018;13:420–7.
31 Wellmon RH, Gulick DT, Paterson ML, *et al.* Validity and reliability of 2 goniometric mobile apps: device, application, and examiner factors. *J Sport Rehabil* 2016;25:371–9.
32 Neto T, Jacobsohn L, Carita AI, *et al.* Reliability of the active-knee-extension and straight-leg-raise tests in subjects with flexibility deficits. *J Sport Rehabil* 2015;24.
33 Chumanov ES, Heiderscheit BC, Thelen DG. The effect of speed and influence of individual muscles on hamstring mechanics during the swing phase of sprinting. *J Biomech* 2007;40:3555–62.
34 Vigotsky AD, Lehman GJ, Beardsley C, *et al.* The modified Thomas test is not a valid measure of hip extension unless pelvic tilt is controlled. *PeerJ* 2016;4:e2325.
35 Goossens L, Witvrouw E, Vanden Bossche L, *et al.* Lower eccentric hamstring strength and single leg hop for distance predict hamstring injury in PETE students. *Eur J Sport Sci* 2015;15:436–42.
36 Thorborg K, Petersen J, Magnusson SP, *et al.* Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scand J Med Sci Sports* 2009;20:493–501.
37 Samozino P, Rabita G, Dorel S, *et al.* A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. 2016;26:648–58.
38 Haugen TA, Breitschädel F, Samozino P. Power-force-velocity profiling of sprinting athletes. *J Strength Cond Res* 2018;1.
39 Morin JB, Samozino P, Murata M, *et al.* A simple method for computing sprint acceleration kinetics from running velocity data: replication study with improved design. *J Biomech* 2019;94.
40 Atkinson TS, Ewers BJ, Haut RC. The tensile and stress relaxation responses of human patellar tendon varies with specimen cross-sectional area. *J Biomech* 1999;32:907–14.
41 Panayi S. The need for lumbar-pelvic assessment in the resolution of chronic hamstring strain. *J Bodyw Mov Ther* 2010;14:294–8.
42 Malliaropoulos N, Bikos G, Meke M, *et al.* Higher frequency of hamstring injuries in elite track and field athletes who had a previous injury to the ankle - a 17 years observational cohort study. *J Foot Ankle Res* 2018;11:7.
43 Noorkõiv M, Nosaka K, Blazevich AJ. Effects of isometric quadriceps strength training at different muscle lengths on dynamic torque production. *J Sports Sci* 2015;33:1952–61.
44 Nagahara R, Naito H, Miyashiro K, *et al.* Traditional and ankle-specific vertical jumps as strength-power indicators for maximal sprint acceleration. *J Sports Med Phys Fitness* 2014;54:691–9. PMID: 24739258.
45 Baar K. Stress relaxation and targeted nutrition to treat patellar tendinopathy. *Int J Sport Nutr Exerc Metab* 2019;29:453–7.
46 Bourne MN, Timmins RG, Opar DA, *et al.* An evidence-based framework for strengthening exercises to prevent hamstring injury. *Sport Med* 2017;48:251–67.
47 Ayala F, López-Valenciano A, Gámez Martín JA, *et al.* Model for hamstring injuries in professional soccer: learning algorithms. *Int J Sports Med* 2019;40:344–53.
48 Bahr R, Thorborg K, Ekstrand J. Evidence-based hamstring injury prevention is not adopted by the majority of champions league or norwegian premier league football teams: the nordic hamstring survey. *Br J Sports Med* 2015;49:1466–71.