Influence of a field hamstring eccentric training on muscle strength and flexibility

A field hamstring injury prevention program

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ABSTRACT

Muscle strength imbalances and poor flexibility are frequently described as risk factors for hamstring injury. Preventive strategies include eccentric exercises, but the influence of field eccentric exercises on these risk factors remains unclear. We investigated the influence of a field hamstring eccentric program on hamstring strength and flexibility. Twenty-seven amateur athletes were randomly assigned to an intervention (n = 13) or control group (n = 14). In the intervention group, participants were involved in 15 sessions of four eccentric exercises. Peak torque, hamstring-to-quadriceps ratios, passive and active flexibility were analyzed. No significant modifications of strength, passive or active flexibility were observed in the control group ($p>0.05$). Hamstring eccentric peak torque (+7.1%) and functional hamstring-to-quadriceps ratios (9.3%) were significantly increased ($p<0.05$) in the intervention group, but not concentric strength ($p<0.05$). Passive straight leg raise was significantly increased by 11.4° (+12.7%, $p<0.001$), but not active flexibility (+3.1%, $p>0.05$). In conclusion, a 6-week eccentric program, including four field exercises for hamstring muscles, is an effective method of improving eccentric strength, functional ratios and, especially, passive flexibility. As this program may be easily implemented in a real-world context, this association of multiple eccentric exercises might be useful in an injury prevention strategy.

Key Words: INJURY PREVENTION, THIGH, MUSCLE PERFORMANCE, FIELD.

INTRODUCTION

Acute hamstring injury is the most prevalent muscle injury in sports involving high-speed running actions [1, 2]. Epidemiological studies report a high injury rate in professional but also in amateur athletes [3]: for instance, amateur male football players have an injury incidence rate of 20.4 to 36.9 injuries per 1000 match and 2.4 to 3.9 injuries per training hour [4]. Several risk factors have been reported such as hamstring muscle weakness and thigh muscle imbalance, poor hamstring flexibility, previous hamstring or other injury, age, muscle architecture [5–9], but their respective contribution to injuries remain unclear.

A number of studies have established that hamstring eccentric training reduces the risk of hamstring strain injury [10]. Conditioning hamstring muscles with eccentric training leads to neuromuscular adaptations that may include multiple elements, such as an increase of biceps femoris long head fascicle length [11, 12], an increase of hamstring muscle strength and/or volume [11, 13–15], or an increase in the hamstrings ability to generate higher levels of torque at longer muscle lengths [13]. More generally, consistent evidence was found that eccentric training is an effective means of improving lower limb flexibility [16]. However, in these studies, flexibility was only assessed in a passive modality. Therefore, the influence of an eccentric training program on active flexibility remains unknown, yet hamstring strains mostly occur during high velocity running and at a substantial elongation stress of the hamstrings [2].

According to a recent meta-analysis, there is strong evidence that eccentric training programs including the Nordic Hamstring Exercise (NHE) decrease the risk of hamstring injuries by up to 51% in the long term [17]. Although NHE is an effective preventive tool, it cannot be considered as the only exercise used to prevent hamstring injury [18]. NHE implies a knee dominant action and is not specific to the terminal swing phase of sprinting [2, 18], which seems to be the most hazardous period for hamstring strain [19]. Therefore, prevention programs for hamstring injuries could probably be more efficient if NHE was associated with other exercises which present different specific characteristics in terms of hip and knee ROM, elongation stress, exercise velocity, contraction intensity, closed or open kinetic chain, unilateral or bilateral modality [2, 20]. Field eccentric exercises such as single leg deadlift, slide leg, Askling's *glider* or fitball flexion are widely used by practitioners, but there is a lack of scientific evidence about their effectiveness to improve muscle strength and flexibility, as well as to reduce injury risk.

The purpose of this study was to investigate the influence of a field hamstring eccentric program on strength, passive flexibility and, originally, active flexibility of hamstring muscles.

MATERIALS AND METHODS

Study design and subjects

As the present study was a randomized controlled trial (RCT), we followed the Consolidated Standards of Reporting Trials (CONSORT) extension for pragmatic clinical trials [21]. The randomization procedure was performed by an independent investigator with an online research randomizer (http://www.randomizer.org). The randomization procedure and all the experimental evaluations (flexibility and isokinetic measurements) were done by two different blind assessors. These assessors were not involved in the field intervention program or in the data analyses.

Sample size was calculated using G*Power Software (Universität Düsseldorf), resulting in a total of 15 subjects (effect size = 0.30; significance level = 0.05; power = 0.80). Thirty-six potential participants were recruited and screened for eligibility criteria. Among this group, 28 satisfied all criteria. To be eligible, subjects had to be males of 18 to 30 years of age, and practice an amateur sport that includes running actions. Exclusion criteria included past hamstring injury, past knee surgery, and ongoing or chronic low back pain. As represented in the CONSORT Flow Diagram (Figure 1), subjects were randomly assigned to either intervention group (IG) or control group (CG).

Of subjects allocated to the IG, one was lost after 3 weeks for personal reasons. The baseline characteristics of these participants, similar for all continuous variables, are presented in Table 1. The study, approved by the local ethics committee (Reference: B707201526715), meets the ethical standards of the journal [22] and participants provided written informed consent.

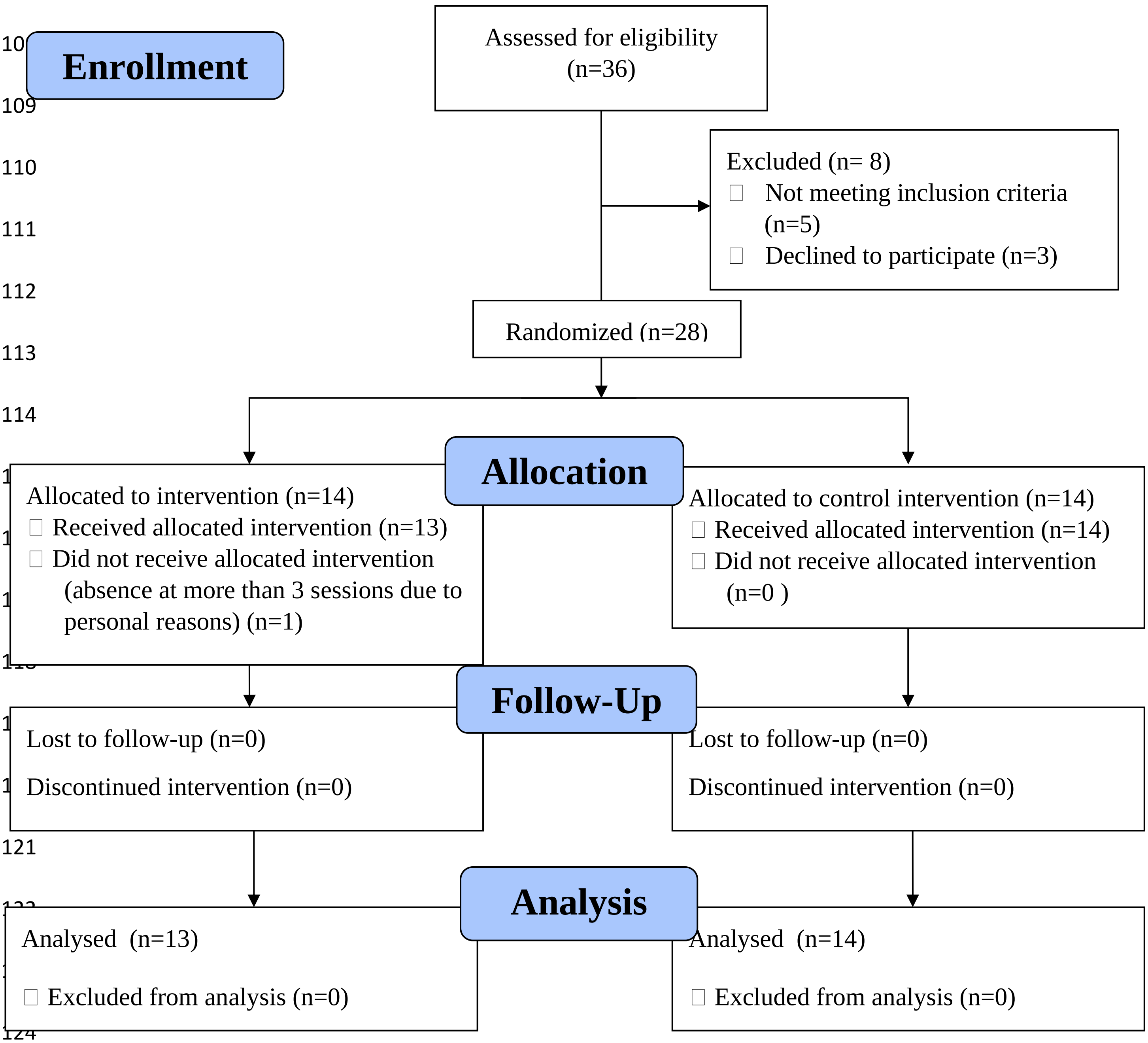

FIGURE 1 CONSORT Flow diagram

TABLE 1. Baseline characteristics by group assignment

	Control Group (n=14)	Intervention Group (n=13)	p Value
Age (years)	23.0±1.7	22.4±2.1	0.58
Height (cm)	1.84±0.11	1.81±0.07	0.37
Mass (kg)	76.5±11.3	75.6±9.8	0.74
Sport duration (hours per week)	4.2±1.9	3.9±1.4	0.32
Type of sport	Football (6)	Football (5)	
	Running (2)	Running (3)	
	Basketball (1)	Basketball (2)	
	Volleyball (2)	Volleyball (1)	
	Rugby (1)	Rugby (2)	
	Baseball (1)		
	Handball (1)		
Hip flexion ROM in passive modality (deg)	82.2±15.8	78.2±15.5	0.47
Hip flexion ROM in active modality (deg)	103.1±14.3	99.7±11.4	0.35
Hamstrings peak torque in ECC30 (N.m)	171.4±37.8	168.6±39.9	0.60
Hamstrings BWN peak torque in ECC30 ($N.m.kg^{-1}$)	2.25±0.52	2.20±0.52	0.54

Note: Values are expressed as means ± SD. ROM: Range of Motion; BWN: Body Weight Normalized; ECC30 = eccentric at $30°.s^{-1}$. The level of significance was set at $p \leq 0.05$.

Experimental procedure

Field hamstring eccentric training

Participants allocated to the IG had to undergo 15 training sessions scheduled during a six-week period (Table 2). Two consecutive sessions were separated by at least 48h and each session was supervised by two physiotherapists. In order to reach a participation in training sessions rate of more than 90%, each participant of the IG could miss a maximum of one session.

TABLE 2. Eccentric exercises protocol for the intervention group

Week	Training frequency per week	Number of exercises per session	Number of sets per exercise	Repetitions per set
1	2	4	2	6
2	2	4	2	8
3	2	4	2	10
4	3	4	3	10
5	3	4	3	10
6	3	4	3	10

During each session, four exercises had to be performed, all without the use of weights or other equipment (except a low friction sock)(Figure 2): NHE, single-leg Roman dead-lift T-drop (SLRDT), slide leg exercise (SLE) and Askling's glider (GL). The selection of these exercises was made first on the possibility to be easily implemented everywhere and secondly that they were balanced between knee/hip dominant action and low/high elongation stress for hamstring muscles. A standardized warm-up was performed in the following order, before starting the eccentric exercises: bicycling for 6 minutes on a cycle-ergometer (75 to 100 W); 3 sets of 15 body weight half squats with 30 seconds of rest intervals; 3 sets of 20 fast foot stepping with 30 seconds of rest intervals. For the NHE, participants started in a kneeling position, with the torso from the knees upward held rigid and straight. A training partner ensured that the participant's feet were in contact with the ground throughout the exercise by applying pressure to the participant's heels/lower legs. The participant then lowered his upper body to the ground, as slowly as possible to maximize loading in the eccentric phase. Hands and arms were used to break his forward fall and to push him back up after the chest had touched the ground [23]. SLRDT was performed in a standing position, on one leg with the knee slightly bent (10 to 20°). Participants had to maintain a neutral lumbar spine position and slowly flexed to end range hip flexion. The back leg remained in neutral hip flexion-extension, and was moved backward as the trunk went forward [20]. SLE required to start lying in the supine position with arms by their side, knees bent, and their heels on two pieces of rug which can easily slide over the floor. The heel on one side is used to weight-bear, with the pelvis off the ground, and the leg is straightened in a slow and controlled manner. The other leg was kept off the floor. When the knee of the working leg was straight, the leg was curled back [20]. The last exercise (GL) was started from a standing position with upright trunk, one hand holding on to a support (wall bars) and legs slightly split. All body weight should be on the heel of the front leg with approximately 10–20° knee flexion. The movement is started by gliding backwards on the other leg (foot on a small rug which can easily slide over the floor) and stopped in maximal ROM. The movement back to the starting position should be performed by the help of both arms, not using the front leg [24]. The order of exercises was modified for each training session, and both dominant and non-dominant legs were trained. In order to maximize loading in the eccentric phase, participants were asked to perform each exercise with the highest intensity. Rest intervals between series or exercises lasted two minutes.

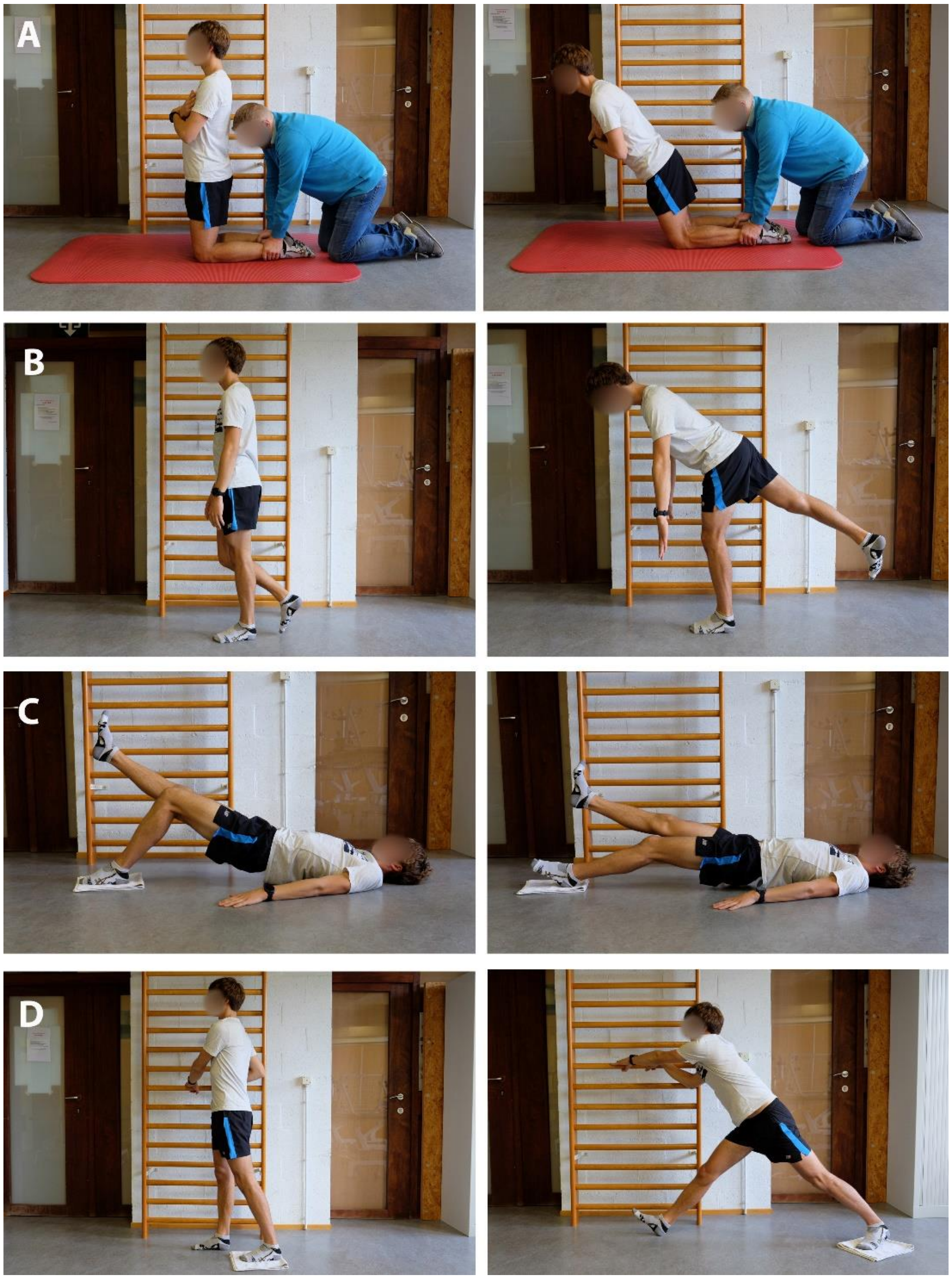

FIGURE 2 Eccentric hamstring exercises. Starting (left column) and ending (right column) positions: (A) nordic hamstring exercise; (B) single-leg Roman dead-lift T-drop; (C) slide leg exercise; (D) Askling's glider

Flexibility and isokinetic assessments

In order to get a valid flexibility and strength assessment, without the bias of fatigue or muscle soreness, subjects were instructed not to engage in intensive training or competition 48h prior to testing. In the IG, the interval between the last training session and the assessments was 72 hours.

The first part of the flexibility test session consisted in a passive straight leg hip flexion. Participants were positioned on a bench in a supine position. A knee brace ensured full extension of the tested leg (dominant leg) and two straps were used to stabilize the upper body and the contralateral leg. To determine the leg dominance, we previously asked to participants "If you would shoot a ball on a target, which leg should you use to shoot the ball?" [25]. The foot of the tested leg was to be kept in a slight plantar-flexed position. An optoelectronic 3D system was used with one marker attached on lateral femoral epicondyle and a second marker on lateral malleolus. The marker's 3D positions were measured using four Codamotion CX1 units (Charnwood Dynamics, Rothley, UK) at a sampling rate of 200Hz. 3D marker positions were filtered through a zero-phase 4th order low-pass Butterworth filter at a cut-off frequency of 10Hz. The examined leg was slowly raised by the investigator. The subject was instructed to relax and say "stop" when the movement reached the maximal ROM. The endpoint was reached when the subject reported a strong but tolerable stretching sensation in the hamstring musculature. One practice trial and three test trials were executed, with a 15 second rest interval The second part of the flexibility test, the active test, was an adapted version of the Askling H-Test, initially developed to complement the usual clinical examination before return to sport after hamstring injury [26]. The whole procedure was identical to the passive test, but the instructions given to the participant were to perform an active straight leg raise (SLR) as fast as possible to the highest point without taking any risk of injury. As well as for the passive test, one practice trial and three test trials were executed with a 15 second rest interval. Passive as well as active flexibility were measured as the largest ROM of the three trials.

An isokinetic test, similar to the one previously described by Croisier et al. [27], was then performed to assess hamstring and quadriceps muscle performance (dominant leg) using a Cybex Humac Norm® dynamometer (CSMI, Stoughton, USA). All measurements were preceded by a standardized warm-up consisting of pedalling on an ergometric bicycle (75 to 100 W) and performing static stretching exercises of the hamstring and quadriceps muscles (20 seconds for each muscle group). The subject was seated on the dynamometer (with 105° of coxofemoral flexion) with the body stabilized by several straps around the thigh, waist, and chest to avoid compensations. The range of knee motion was fixed at 100° of flexion from the active maximum extension. The gravitational factor of the dynamometer's lever arm and lower leg-segment ensemble was calculated by the dynamometer and automatically compensated for during the measurements. An adequate familiarization with the dynamometer was provided in the form of a further isokinetic warm-up at 120°.s^{-1} (ten sub-maximal repetitions followed by six repetitions progressively increased to a maximal performance) during warm-up. Moreover, before assessment, three preliminary repetitions routinely preceded each test speed. Verbal encouragement was given, but the subject did not receive any visual feedback during the test. The protocol included concentric exertions (angular speeds of 60°.s^{-1} (three maximal repetitions) and 240°.s^{-1} (five maximal repetitions)) of both hamstring and quadriceps muscles. Afterward, flexor muscles were subjected to eccentric angular speed of 30°.s^{-1} (three maximal repetitions).

Between series, a one-minute rest interval was systematically required. The result analyses included the absolute peak torque (PT; in N.m) and body weight normalized peak torque (BWN PT; in $N.m.kg^{-1}$). A conventional hamstring-to-quadriceps (H:Q) peak torque ratio was established for the same mode and speed of concentric contraction. An original mixed ratio associated the eccentric performance of hamstring muscles ($30°.s^{-1}$) and the concentric action of the quadriceps muscles ($240°.s^{-1}$) [27].

Statistical analyses

Statistical analysis was performed using Statistica V.11.0 Software (StatSoft Inc.). As the Shapiro-Wilk W test showed that the data were normally distributed, data are presented as mean ± standard deviation. Baseline demographic and clinical variables were compared between both groups using independent Student t-tests for continuous data. Statistical significance was accepted at $p<0.05$. For each variable, the percentage of change compared to baseline was calculated. Effect sizes of the mean group differences were calculated as the Cohen *d* and classified as small (0.2), medium (0.5) and large (0.8). Responsiveness to the eccentric training was determined using the typical error criteria (TE) in the IG group, with the following equation: $TE = SDdiff/\sqrt{2}$, in which SDdiff is the standard deviation of the difference scores observed between the pre- and post-tests [28]. A non-responder for flexibility and isokinetic parameters was defined as an individual who failed to demonstrate an increase or decrease (in favor of beneficial changes) that was greater than two times the TE away from zero.

RESULTS

In IG, nine participants fulfilled all the 15 sessions, and four participants had one absence (14 completed sessions): compliance was therefore excellent with a participation rate of 98%. No participant of the CG was lost to follow-up. Eight participants in IG reported light to mild delayed onset muscle soreness (DOMS) 24 to 48 hours after the first or the second session, but the program could be achieved without any modification.

Flexibility

In CG, ROM during both passive and active SLR did not significantly change from pre to post ($p>0.05$). In IG, ROM during passive SLR was significantly increased by 11.4° (+12.7%; $p<0.001$, and had a large size effect ($d=0.81$)), which was not observed during active SLR (+3.1%, $p>0.05$) (Figure 3). After the eccentric training, two participants in the IG (15%) were considered as non-responders for the passive flexibility (increase less than 4.8°), and six participants (46%) did not respond positively for the active modality (increase less than 2.7°).

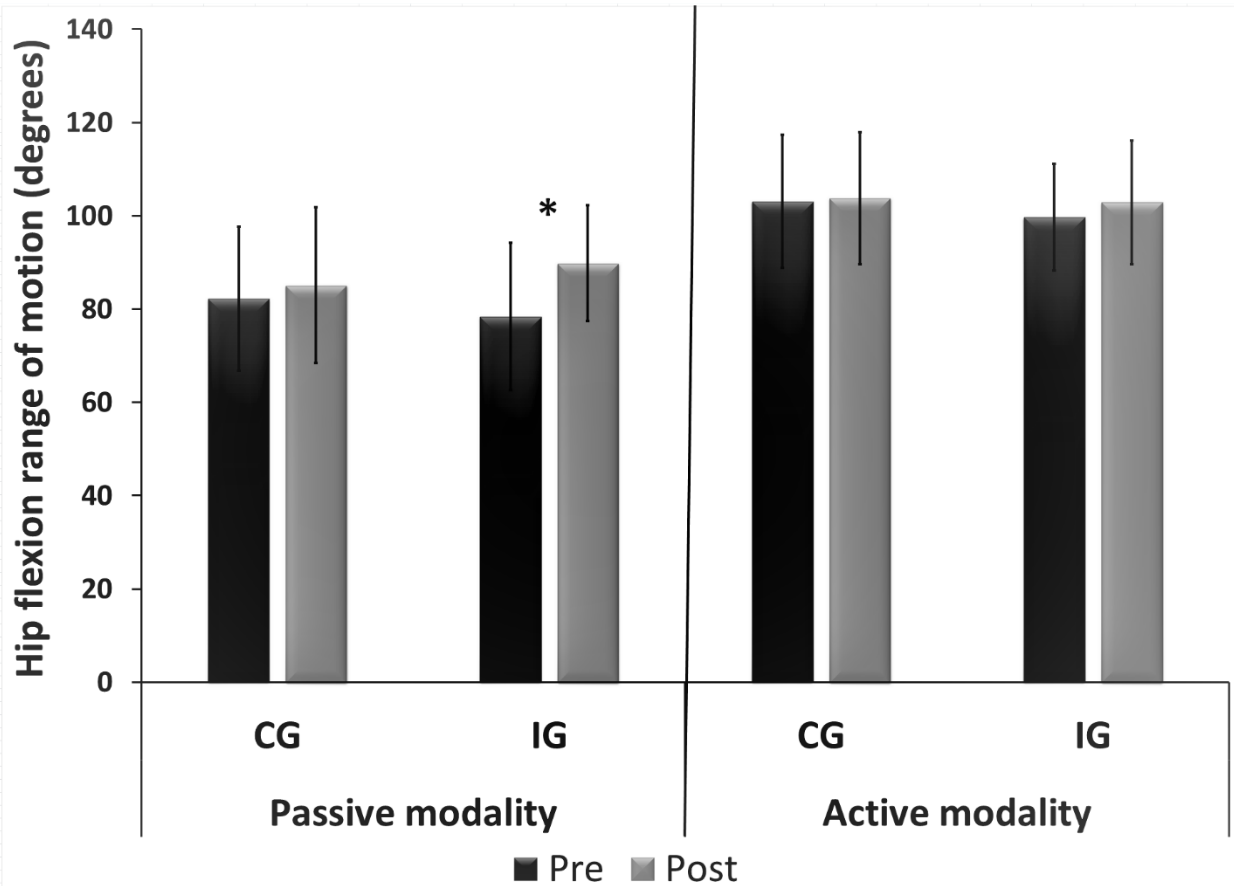

FIGURE 3 Mean (±1 SD) values for passive and active hip flexion ROM in the control (CG) and intervention (IG) groups before (Pre) and after (Post) the intervention. *****: p<0,001

Strength

The isokinetic hamstring strength measures are presented in Table 3. In CG, no significant difference of hamstring strength or H:Q ratios were found between pre and post tests (mean difference: ± 0.3 to 3.5%; $p>0.05$). In IG, after the 6-week eccentric training, peak torque was significantly increased ($p<0.05$) in ECC 30 by 7.1%, and in BWN ECC 30 by 8%. No significant improvements of CON strength and CON H:Q ratios (60 and 240°.s^{-1}) were observed ($p>0.05$), but the mixed ECC30/CON240 ratio was significantly increased by 9.3%. Size effects of the aforementioned significant differences between pre and post tests were small to medium (range 0.34-0.67).

Regarding CON strength, the IG presented 8 responders (62%) and 5 non-responders (38%); regarding ECC strength, 11 responders (85%) were identified, versus two non-responders (15%). Regarding H:Q ratios, 5 (38%) and 2 (15%) participants did not respond positively on CON and ECC ratios, respectively.

Quadriceps strength was not modified in IG or CG between pre and post tests for each tested parameter ($p>0.05$).

TABLE 3. Descriptive data of isokinetic hamstrings assessment (dominant leg): absolute peak torque, peak torque to body weight and hamstrings-to-quadriceps ratios for the control and intervention groups before (Pre) and after (Post) the intervention

	Control group (n=14)		Intervention group (n=13)	
	Pre	Post	Pre	Post
Peak torque (N.m)				
CON60	121.8±22.8	119.4±19.7	115.6±24.6	123.9±24.1
CON240	81.7±15.1	83.1±22.2	76.4±15.4	81.7±14.9
ECC30	171.4±37.8	165.8±42.1	168.6±39.9	**181.4±36.1**
Body weight normalized peak torque ($N.m.kg^{-1}$)				
CON60	1.63±0.38	1.59±0.32	1.54±0.34	1.69±0.33

CON240	1.07±0.20	1.09±0.28	1.04±0.21	1.07±0.18
ECC30	2.25±0.52	2.17±0.55	2.20±0.52	**2.39±0.47**
Hamstrings-to-quadriceps ratios				
CON60	0.54±0.09	0.53±0.10	0.57±0.12	0.61±0.12
CON240	0.59±0.13	0.61±0.13	0.58±0.10	0.64±0.11
ECC30/CON240	1.23±0.19	1.19±0.23	1.26±0.24	**1.39±0.28**

Note: CON60 = concentric at 60°.s^{-1}; CON240 = concentric at 240°.s^{-1}; ECC30 = eccentric at 30°.s^{-1}. Values in bold indicate significant difference compared with pre tests (p<0.05).

DISCUSSION

The aim of the present RCT was to evaluate the influence of a 6-week, field hamstring eccentric program on strength and flexibility, which are considered as risk factors for hamstring injuries [19]. The results showed that, without additional stretching exercises, the eccentric training improved passive hamstring flexibility, but the ROM during the active flexibility test was not modified; moreover, this training program led to a significant increase of both hamstring eccentric strength and the mixed ECC30/CON240 ratio.

The increase in ROM after the eccentric program (+11.4°, large effect size) appears similar to results from Nelson and Bandy (+12.8°)[29], but larger than those from Potier et al. (+6.9°)[12]. In comparison to these studies which also examined hamstring muscles flexibility, we used a different methodological approach. In the study from Potier et al. [12], subjects had to perform exercises positioned in prone on a bench of a hamstring leg curl machine. This prone position during the strengthening program does not allow hip flexion movement and, in consequence, the total hamstring elongation stress cannot be considered as maximal. We hypothesize that flexibility gains are greater if eccentric exercises combine hip flexion and knee extension: in our study, the larger increase in ROM may be due to the inclusion of two exercises that require a maximal elongation stress (SLRDT and GL). Nelson and Bandy [29] used eccentric exercises at maximal elongation stress, but they incorporated a static hold at end range during five seconds, which can therefore be considered as a mix of traditional eccentric training and static stretching [16]. The most likely mechanism by which flexibility increases after eccentric training could be sarcomerogenesis, as described in animal models [30]. The addition of sarcomeres in series leads to the production of peak torque at a higher joint angle [31], and also increases muscle fascicle length [12]. Furthermore, eccentric training may also improve eccentric velocity, possibly by enhancing the storage and utilization of elastic energy and/or contribution of facilitatory (e.g. stretch) reflexes [32]. As the superiority of stretching compared to eccentric exercises on flexibility has not been established [16, 29], one may question the need for stretching. However, excluding stretching exercises could be erroneous because stretching and eccentric exercises produce distinct tendon adaptations: tendon stiffness has been demonstrated to decrease or stabilize after stretching training [33], while stiffness increased after high-load eccentric (or other contraction type) training [34, 35], as well as tendon cross-sectional area [35]. As decreasing the stiffness of a tendon has been shown to increase its energy capacity [33], stretching exercises should still be incorporated in the prevention of tendon injuries.

To our knowledge, this study is the first to evaluate the influence of an eccentric program on active flexibility. Poor hamstring flexibility has been suggested as a risk factor for hamstring injury

[36, 37], but, in previous studies on this topic, only passive flexibility was considered while running cycles during sprinting may imply peak angular velocity greater than 1000°.s^{-1} [38]. Therefore, assessing hamstring flexibility in a ballistic movement, close to the sprinting angular velocities, could represent a more relevant approach. Originally, Askling et al. [26] developed the H-test for detecting deficits in athletes with hamstring injuries in order to provide additional information to the clinical examination before going back to full training and competition. We adapted the H-test with a 3D system that has been used in past biomechanical studies with excellent reliability [39, 40]. Results showed that active flexibility was greater than passive flexibility in the same proportions than in Askling's study (+20-23%) [26], but with shorter ROM (mean: 101.4° versus 117.3°). This difference could be explained by a lower passive flexibility in our cohort (mean: 80.3° versus 90.4°). Surprisingly, while passive flexibility was largely increased consecutively to the eccentric program, we found no improvements in active flexibility. One possible explanation for this is that none of the four exercises was realized at high velocity, leading to a lack of specific adaptations during an explosive movement like a H-test. Improvements in hamstring active flexibility (particularly during an explosive action) could be of interest for an athlete. From a performance perspective, a high dynamic hamstring flexibility may allow an ample stride during a sprint activity. If the goal of an athlete is to increase the ROM of the swing phase of a running cycle when sprinting, this study clearly shows that an eccentric program that only includes exercises realized at low to moderate velocity may not be sufficient. It would probably be necessary to practice athletic sprinting exercises or high-velocity eccentric exercises, even if this needs further investigation.

After the 15 sessions of the intervention program, significant improvements of eccentric hamstring strength (+7.1 to 8%) were observed. Orishimo and McHugh [41] observed similar increases (+9%) after a 4-week eccentric home-based program but hamstring strength was only assessed in an isometric modality. Indeed, hamstring injuries typically occur in the terminal swing phase during sprinting, where hamstring muscles have to decelerate knee extension with an eccentric contraction in a lengthened position [4]. Therefore, the assessment of hamstring muscle strength in an eccentric modality is probably more relevant [27]. With eccentric and concentric strength improvements of 16 to 38% and of 15 to 20%, respectively, , previous studies have found a superior efficiency of eccentric exercises than the present one[19, 42-45], despite high intensity exercises such as NHE or, particularly, SLE [20]. In a majority of these studies, eccentric exercises were performed with the use of specific devices or weights allowing to monitor the load for each repetition. We hypothesize that the moderate gains in eccentric and the non significant gains in concentric strength are related to the absence of objective feedback about the intensity of each exercise. For example, Geremia et al. and Baroni et al. [35, 46] used an isokinetic dynamometer for the eccentric training and could therefore receive an instantaneous feedback about the intensity of each exercise. If the intensity of each repetition was not considered as maximal, the examiners could inform the subjects to perform the exercise at a higher intensity. In our study, although participants were asked to perform each exercise with the highest intensity, the supervisors could not receive an objective feedback, because the exercises were done without the use of specific devices. This may be of importance for athletic trainers and therapists: a maximal intensity during "on field" exercises, with body weight as resistance, may possibly not be achieved.

Although it has not been investigated in this study, another positive consequence of eccentric exercises is the shift of peak force production in the direction of longer muscle lengths. It has been proposed that athletes who produce peak tension at shorter muscle length are more likely to suffer an acute muscle injury [47]. A shorter optimum length would result in a decrease in the muscles "safe" operating range, thus increasing the risk of injury. This shift in optimum length after eccentric exercise may also positively affect athletic performance [48]. Indeed, if the muscle-tendon unit is more compliant at the beginning of the stretch, it would be possible to store more elastic energy. Also, if stiffness increases at the end of the stretch, more energy could be released at higher rate. Thus, performance of the stretch-shortening cycle and, as a consequence, athletic performance, would be greatly enhanced [48].

Hamstrings-to-quadriceps imbalances have been suggested to be an injury risk factor [27]. According to Croisier et al. [27], a selected cutoff less than 0.80 for a functional H:Q ratio (on Cybex®) may be considered as an imbalanced strength profile. The population from this study did not present any imbalance (1.26±0.24) at baseline, and it was not possible to determine whether the eccentric program may have normalized an imbalanced strength profile. After the eccentric intervention, this study showed a significant increase of the functional H ECC30/Q CON240 (+9.3%), without any modification of quadriceps strength. Mean functional ratio was increased to 1.39, which is close to a "no injury zone" of functional ratios superior to 1.40 as described in a large prospective study from an elite football population [27].

The results of this study should be considered according to potential strengths and limitations. To our knowledge, this research was the first experimental study examining the influence of eccentric hamstring exercises on active flexibility during an explosive movement combining hip flexion and leg extension. A second important positive aspect of the study is that the four exercises of the program do not require specific material or devices (except a low friction sock). Therefore, they can easily be implemented around sport fields in injury prevention programs, especially in amateur sports. Third, compliance to the program was excellent (98%) and may lead to conclusive evidence [49]. Among limitations, participants were engaged in a regular practice of one sport activity (seven different sports for the whole cohort) at an amateur level. Therefore, we do not know if high level athletes or a more homogeneous sport population (e.g. football players only) would present same outcomes. In addition, as we did not include women in the study, we do not know if similar results would be obtained in a female population. Finally, as stated above, no eccentric exercises at high angular velocity were included in the program. One may suggest that adding to the training program specific high velocity eccentric exercises such as *Fitball flexion exercise* or *Kettle bell swing exercise* [20], could potentially induce larger improvements in the H-test. However, it was shown that the training adaptations observed after eccentric training were independent from the velocity exercise [2]. For example, Iga et al. [44] demonstrated that a four-week training of NHE – a low movement velocity exercise – produced the same improvements in peak torque at 60, 120 and 240°.s^{-1}. The adaptations observed after an eccentric strength program performed at slow angular velocity may then protect hamstring muscles from the fast elongation occurring during the swing phase of sprinting. Therefore, for optimizing hamstring injury prevention, the exercises should be performed at slow or moderate angular velocity [2].

CONCLUSION

This study demonstrated that a 6-week eccentric program, including four field exercises for hamstring muscles, is an effective method of improving several hamstring injury risk factors such as passive flexibility, eccentric strength and functional ratios. Performing such a program with high-risk athletes (e.g. football players or track and field athletes) might therefore be useful in a hamstring injury prevention strategy. Furthermore, as this eccentric program did not require any specific equipment, it can be easily implemented in a real-world context, especially in amateur athletes. Further studies are needed to determine if this eccentric training may decrease the injury incidence in a high risk population.

Conflict of interest

The authors declare no conflict of interest.

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