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Impact of Askling L-PROTOCOL on Biceps Femoris Architecture, Hamstring Flexibility and Sprint Performance

I have no corrections.

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ABSTRACT

Eccentric training has been shown to be important for hamstring strain injuries rehabilitation and prevention. The Askling L-PROTOCOL (L-P), comprising three exercises aimed at eccentric training and hamstring lengthening, was shown to improve this injuries recovery and relapse times in comparison with other traditional exercise-based protocols. However, the causes of these results remain unclear. This study looks at the impact of an 8-week L-P followed by 4 weeks of detraining on the architecture of the biceps femoris long head, hamstring flexibility and sprint performance. Twenty-eight healthy individuals were divided into two groups: an experimental group, which carried out the L-P, and a control group with no training. Muscle architecture was measured using 2D ultrasound, hamstring flexibility using goniometry and sprint performance using sports radar equipment before (M1) and after (M2) the training period and after detraining (M3). No significant changes were observed between M1 and M2 in the experimental group with regard to fascicle length ($t=-0.79$, $P>0.05$), theoretical maximum speed ($t=-1.43$, $P>0.05$), horizontal force ($t=0.09$, $P>0.05$), force application during sprint running ($t=-0.09$, $P>0.05$) and horizontal power ($t=-0.97$, $P>0.05$), but, however, changes were observed in hamstring flexibility ($t=-4.42$, $d=0.98$, $P<0.001$) returning to pre-training values after detraining period ($t=-1.11$, $P>0.05$). L-P has been shown to be an eccentric protocol of moderate intensity and easy implementation that could be interesting to include throughout a sports season.

Introduction

In sports involving high-speed running with accelerations, decelerations and changes of direction, the muscles that are injured the most are the hamstrings, which has serious consequences for athletes, such as a decline in performance, an increase in the amount of time spent away from sports activities, a risk of incurring further injury and financial losses [1, 2]. Hamstring strain injuries (HSI) have a high rate of recurrence [3], with a strong association between previous injuries and the risk of subsequent injuries being observed [4]. In spite of efforts to prevent and treat them[5, 6], their occurrence has not lessened [2, 7].

Their cause remains ill-defined, but it has been observed that HSI usually occur when the muscles are lengthened to a point beyond where the peak torque occurs [8]. This usually happens more frequently in sprinting [9, 10], the biceps femoris long head (BFlh) being the site most commonly affected [10]. It is during the swing phase of the run that maximum contraction is required of the hamstrings as they are lengthened at high speed to their maximum length, this being their most critical point [11].

Two modifiable injury risk factors [12, 13] are altered by HSI: their capacity to generate eccentric force [14, 15], and the shortening of the BFlh fascicle length (FL) [16]. The lack of eccentric training and lengthening in early rehabilitation could lead to residual deficits and an increase in the risk of a relapse [17] which is observed in previously injured muscles[17, 18].

Eccentric loading and long-length exercises reduce the risk of HSI [19, 20]. This type of exercises increase knee flexor strength [21] and BFlh FL, decreasing the pennation angle (PA) and maintaining muscle thickness (MT) in uninjured individuals [21, 22] and accelerate recovery time when enhanced in rehabilitation [23]. This type of training would increase the number of serial sarcomeres, a mechanism that would allow the muscles to work at longer lengths [24], thus reducing the amount of work done in the descending and more unstable limb of the length-tension curve [25]· It has been systematically reported that eccentric training increases the optimum length of tension development [25–27], this being linked to a reduction in the risk of HSI [28], as well as to an improvement in the strength of the lower limbs [21, 27, 29] and small-to-medium improvements in sprint performance [29]. However, we should highlight that the effects of this type of training can be negatively affected after a subsequent detraining period [21, 22].

One of the most used eccentric exercises of hamstring muscles is the Nordic Hamstring Exercise (NHE) [19–22, 25, 29], whose efficiency in reducing HSI has been verified [19, 30]. Despite of this, it has also been criticised for being an exercise that is difficult to adapt to athlete's training dynamic during the season [31]. Thus, other authors have tried proposing alternatives to the NHE. Along these lines, Askling et al. [23, 32] proposed an eccentric training protocol for HSI called the L-PROTOCOL (L-P), which consists of exercises focused on loading the hamstring muscles during extensive lengthening. The L-P consist of three eccentric exercises: Extender (EX), to increase hamstring muscle flexibility; Diver (DV), to increase their strength while stabilising the pelvis and trunk; and, lastly, Glider (GL), which strengthens the muscles as well as lengthening them in a controlled way. These authors proved the efficiency of the L-P, leading to a reduction in the recovery time after HSI in comparison with a protocol of conventional non-eccentric exercises [23, 32]. Moreover, during a subsequent 12-month monitoring period, no relapses were recorded among the individuals who took part in the L-P, this circumstance differing substantially from the relapse rates reported in literature [33].

The efficiency of the L-P is believed to stem mainly from the fact that it stimulates the hamstring muscles during a dynamic maximum lengthening exercise involving the movement of hip and knee articulations. Furthermore, L-P could influence the improvement of hamstring flexibility, another variable that has also been shown to be statistically associated with a higher incidence of HSI [34]. However, the mechanisms behind its efficiency have not yet been totally elucidated. An initial approach was one adopted by Severini et al. [35], which characterised the neuro-mechanical profile of L-P exercises. Said authors performed a detailed kinematic and electromyographic analysis of said exercises, observing that they cause a submaximal contraction in the hamstring muscles (up to 60 % of MVC in the GL) at a work point similar to the thrust phase of the sprint (around 62 ° hip flexion and 23 ° knee flexion). Furthermore, their co-activation analysis highlighted that, through the combination of passive stretch and active eccentric contraction, the hamstrings are trained to co-activate using similar structural modules employed differentially to drive the movement or stabilise it.

In addition, the analysis presented by the abovementioned authors does not study how the L-P impacts chronically on other relevant HIS factors. Consequently, the aim of this study was to evaluate the impact of an 8-week L-P on followed by 4 weeks of detraining on the architecture of BFlh, hamstring flexibility and sprint performance. The hypothesis is that, due to their moderate eccentric intensity and the maximal dynamic elongation of the structures (a) L-P will not significantly affect LF, PA or MT, (b) will not influence sprint performance, (c) will elongate the hamstring structures and (d) the hamstring structures will not maintain this elongation after a period of detraining.

Methods

Subjects

Twenty-eight male individuals (age: 25.1 ± 3.1 years, height: 1.77 ± 0.11 m, weight: 75.7 ± 11.6 kg) were recruited for this randomized control trial. To calculate a-priori the sample size, statistical software (G * Power; University of Düsseldorf, Dusseldorf, Germany) was used. Given the study design (2 groups, 3 repeated measures), the effect size 1.05 based on a previous research investigating the effects eccentric training on BFlh FL [21, 22], $\alpha < 0.05$, the nonsphericity correction € = 1 and a desired power ($1-\beta$ error) = 0.80, the total sample size resulted in a minimum of 11 participants required in each condition. It was decided to include 14 participants in each group to prevent possible drop-outs from the training protocol. All of the participants were physically active and did some kind of sports activity regularly (team sports, martial arts and athletics) at different levels. Exclusion criteria included: a) not to have had any HSI in the 12 months prior to the study, b) no signs and symptoms of other causes of posterior thigh pain at the start of the experimental phase. All of the participants were informed of its characteristics and agreed to take part voluntarily, signing the corresponding informed consent form. All of the measurements and data collection took part at Vigo University's Faculty of Education and Sports Sciences (Pontevedra, Spain). The study complied with the current ethical regulations for research [36], was approved by the by the Research Ethics Committee of the Galician Regional Government's (Xunta de Galicia, Spain) Health Department (register: 2018:238) and conformed to the latest revision of the Declaration of Helsinki.

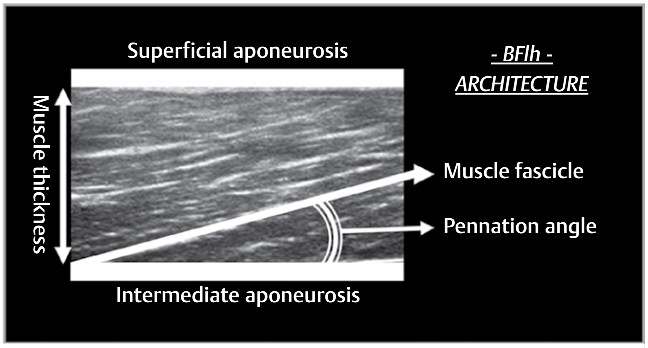
Design

This longitudinal training study took place over 15 weeks. In weeks 1 and 2, the participants had 4 sprint preparation sessions (day 1, 3, 5 and 8) to improve their technique and performance. In week 2, they were subjected to an initial measurement session (M1: day 10) which consisted of a 2D ultrasound, a hip goniometry and a 30 m sprint in order to determine the BFlh architecture, the flexibility of the hamstring muscles and the sprint performance, respectively. When the M1 was completed, the participants were randomly assigned to one of two groups: experimental (EG, n = 14) or control (CG = 14). Once assigned a group, and over two sessions (day 12 and 13), the EG participants familiarised themselves with the characteristics and execution of the L-P exercises in order to guarantee their technical quality. Between weeks 3 and 10, the EG participants developed an L-P following the methodology described by Askling et al. [32], while the members of the CG continued to carry out their standardised daily physical activity. Participants who missed more than one training session per week would be excluded. Between weeks 11 and 14, the EG underwent a period of detraining, in which they stopped doing the L-P. The protocol for measuring the variables was repeated for both groups in week 11 (M2: day 71), 48 hours after the last training session carried out by the EG, and in week 15, after the period of detraining (M3: day 105). All of the evaluations were made at the same time of the day and under the same conditions for all of the participants.

Assessment of the BFlh architecture

The architectural variables were determined from ultrasound images obtained along the longitudinal axis of the muscle belly, using a 2D B-mode ultrasound scanner (frequency, 12 Mhz; depth, 8 cm; field of view, 14 × 47 mm) (GE Healthcare Vivid-i, Wauwatosa, USA). The measurement site was the halfway point between the ischial tuberosity and the posterior knee joint fold, along the line of the BFlh. To ensure replication, at M1 this reference points and the measurement site were marked with a permanent marker and photographed. In M2, this image was retrieved to orientate the measurement site. Three ultrasound images were obtained were taken after at least 5 minutes of inactivity, with the participant in prone position, and the hip and knees neutral and fully extended [21, 22]. The probe was aligned longitudinally and perpendicular to the back of the thigh on the exploration area of the participant's skin, on which transmission gel had been smeared, and was handled carefully in order to keep pressure on the skin to a minimum and not alter measurement precision [37] with the subject at rest.

Image analysis was carried out using MicroDicom software 0.7.8, Bulgaria. Following the procedure of Blazevich, Gill and Zhou [38], six points were digitised for each one of the images. The best fascicle (i. e., the fascicle that could be seen to the ultrasound probe field-of-view end) in each image was used for MT, PA and FL analysis. MT was defined as the distance between the superficial aponeurosis and the halfway point of the BFlh and was calculated through the mean value of four parallel lines drawn at right angles between the superficial and deep aponeuroses along each ultrasonography image. PA was defined between the intermediate aponeurosis and the direction of a muscle fascicle previously identified in the image (▶ **Fig. 1**). The aponeurosis angle (AA) was determined as the angle between the line marking the aponeurosis and a horizontal line tracing the length of the image captured [38]. Lastly, the FL was defined as the length of the muscle fascicle between both aponeuroses. Given that the full length could not be observed in the probe's field of view, an estimation was made using the equation validated by Blazevich et al. [38].



▶ **Fig. 1** Two-dimensional ultrasound image of the Biceps Femoris long head (BFlh) taken along the longitudinal axis of the posterior thigh. From these images, the superficial and intermediate aponeuroses could be determined, as well as the muscle thickness and fascicle angle with respect to the aponeurosis. The estimations of the fascicle length can be performed through a trigonometric calculation, using the muscle thickness and the pennation angle.

$$FL = \text{sen}\,(AA + 90^\circ) \times MT/\text{sen}\,(180^\circ - (AA + 180^\circ - AP))$$

Where FL = fascicle length, MT = muscle thickness, AA = aponeurosis angle and PA = pennation angle.

FL was shown in absolute terms (cm). Mean values were obtained from three ultrasound images for each muscle in order to determine FL and PA (i. e., analyses were based on a total of three fascicles per muscle), as well as MT. All of the images were collected and analysed by the same evaluator (MFJ) with previous experience [22], who was at all times blind to the participants' identifiers during the analyses.

Flexibility of the hamstring muscles

Flexibility deficit has been identified as a relevant factor in the occurrence of HSI [34]. Individuals were measured in supine position. The examiner lifted the leg, bending the hip and maintaining knee extension, measuring the hip angle with a standard goniometer [34] and avoiding any aberrant pelvic movements. The axis of the goniometer was placed over the greater trochanter of the femur. The stationary arm was positioned in horizontal, parallel to the bed, and the mobile arm was placed on the thigh over the lateral epicondyle of the femur. Three measurements were taken for each participant with a rest interval of 30 s between measurements. The average value was obtained to determine the final value in sexagesimal degrees.

Sprint performance

Sprint performance was measured using a manual radar gun (Stalker ATS II, Minneapolis/sampling rate 46.875 Hz) positioned on a tripod 10 m behind the individual and at a height of 1 m which corresponded approximately to his/her centre of mass [39]. Using the data obtained by the radar in each sprint and establishing the force-velocity relationships, we were able to calculate (for details, see Somozino et al. [40]): theoretical maximum velocity (V0), horizontal force (Fh0), ratio of force application during the sprint (RFmax) and horizontal power (Pmax). In each measurement session (M1-M2-M3), each individual performed 3 30-metre sprints with a 2-minute rest between them and a prior standardised 15-minute warm-up based on continuous runs, dynamic stretches and running technique. The recorded value was the average of the three sprints, since a better reliability of the measurements can be achieved by tracing the average of two or three sprints, rather than the best of the three sprints [41].

L-PROTOCOL

The EG individuals completed 8 weeks of training based on the L-P described by Askling et al. [23, 32] and comprising three exercises (▶ **Figs. 2, 3** and ▶ **4**).

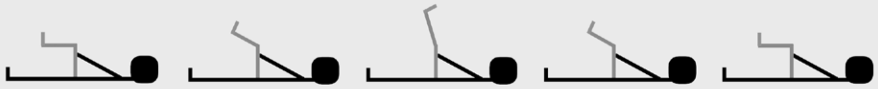
The weekly training frequency can be observed in ▶ **Table 1**. The entire process was supervised by the researchers in order to guarantee its proper execution and intensity.

Soreness

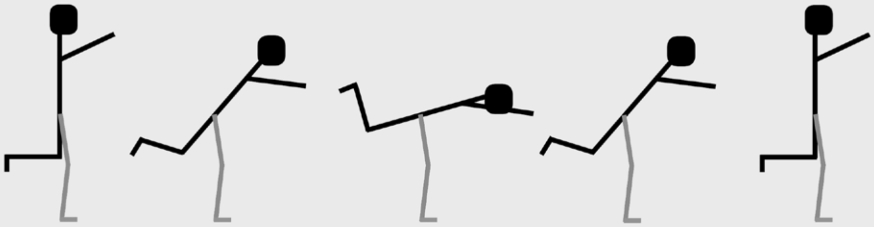
The subjective perception of soreness was recorded before each training session. Participants were asked "How sore do you feel in your hamstrings?" and rated their soreness on a 10-point Likert Scale (1 = No Soreness, 3 = Minimal Soreness, 5 = Moderate Soreness, 8 = Very Sore, 10 = Extremely Sore) [21, 42].

Statistical analysis

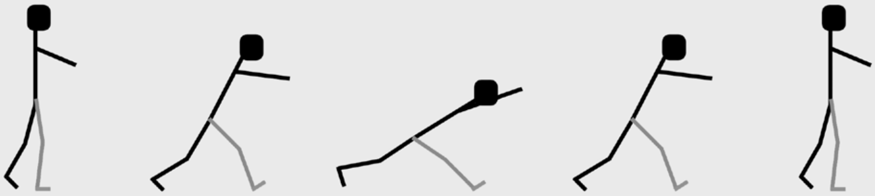
Normal distribution of data was verified via the Shapiro-Wilk test and homoscedasticity via the Levene test. The Greenhouse-Geisser correction was used when the assumption of sphericity was violated ($P < 0.05$ for Mauchly's test of sphericity). A repeated measures ANOVA was used to determine the changes induced by training in each of the muscle architecture variables (FL, MT and PA), the flexibility of the hamstring muscles and sprint performance (V0, Fh0, RFmax and Pmax). The within-subjects variable was time (M1-M2-M3) and the between-subjects variable was the group (EG, CG). In addition, post-hoc t-tests with the Bonferroni correction were used to establish comparisons between variables in the different pairwise measurements (M1-M2, M1-M3 and M2-M3). Significance was set at $\alpha < 0.05$ and, where necessary, Cohen's d was provided to establish the measure of effect size. Repeatability of ultrasound and flexibility measures was evaluated using a two-way



▶ **Fig. 2** EXTENDER (EX). The participant lies supine holding the involved thigh with the hip flexed at approximately 90 ° and performs slow knee extension, stopping if there is any pain. 3 series × 12 repetitions twice a day, every day.



▶ **Fig. 3** DIVER (DV). The participant stands on one leg with the knee flexed at 10–20 °. The arms are held out when the uninvolved leg is raised behind the body, with the knee kept at 90 % of flexion, attempting to raise it as high as possible. 3 series × 6 repetitions once every two days.



▶ **Fig. 4** GLIDER (GL). The participant begins with one hand on a bar or support, gliding backwards with the uninvolved leg and stopping before pain is felt in the involved front leg. 3 series × 4 repetitions once every three days.

▶ **Table 1** Weekly frequency of L-PROTOCOL exercises for 8 weeks.

Day of the week	Exercise or exercises
monday	EXx2 (1 morning + 1 evening)
tuesday	EXx2 + DVx1
wednesday	EXx2 + GLx1
thursday	EXx2 (1 morning + 1 evening)
friday	EXx2 + DVx1
saturday	EXx2 + GLx1
sunday	break

EX = extender exercise, DV = diver exercise, GL = glider exercise.

▶ **Table 2** Characteristics of participants (mean ± standard deviation).

Group	N	Age (years old)	Weight (kg)	Height (m)
EG	14	25.4 ± 2.9	74.6 ± 12.4	1.75 ± 0.09
CG	14	24.8 ± 3.2	76.8 ± 10.9	1.79 ± 0.11

random effects intraclass correlation coefficient model, i. e., ICC(2,1). The analyses were performed with SPSS 25.0 for MacOS software (IBM Corporation, Chicago, IL).

Results

No significant differences in age, height or body mass were observed between the groups ($P > 0.05$) (▶ **Table 2**). The compliance rate was excellent for the EG (99.5 %).

Reliability analysis demonstrated high test-retest reliability for FL (ICC = 0.89), PA (ICC = 0.91) and MT (ICC = 0.99) measures using ultrasound imaging and flexibility (ICC = 0.98) measured goniometry. ▶ **Table 3** sets out the results obtained, bearing in mind the different variables measured in the sample.

Muscle architecture

The FL was not shown to be affected by the L-P, $F(1.12–14.55) = 0.84$, $P > 0.05$, $n^2_p = 0.061$. With regard to the pairwise comparisons derived from the post-hoc analysis, no significant changes were observed either in the EG ($t = -0.79$, $P > 0.05$) or the CG ($t = 0.81$, $P > 0.05$) after the 8 weeks of training or the 4 weeks of detraining: EG ($t = -1.02$, $P > 0.05$), CG ($t = -0.93$, $P > 0.05$).

Neither was the PA shown to be affected by the L-P, $F(1.03–13.45) = 0.03$, $P > 0.05$, $n^2_p = 0.002$. No significant changes, either in the EG ($t = 0.18$, $P > 0.05$) or the CG ($t = 0.09$, $P > 0.05$), were observed between M1 and M2, or between M2 and M3: EG ($t = -0.22$, $P > 0.05$), CG ($t = -0.39$, $P > 0.05$).

The MT showed a similar trend, $F(1.04–13.52) = 1.16$, $P > 0.05$, $n^2_p = 0.08$. No significant changes in the EG ($t = -0.92$, $P > 0.05$) or the CG ($t = -0.31$, $P > 0.05$) were observed between M1 and M2, or between M2 and M3: EG ($t = 1.26$, $P > 0.05$), CG ($t = 0.19$, $P > 0.05$).

Flexibility of hamstring muscles

Hamstring muscle flexibility was affected by the L-P, $F(2–26) = 17.57$, $P < 0.05$, $n^2_p = 0.58$. In the pairwise comparisons it can be seen that in the EG there was a significant increase in the degrees of hip flexion with the knee extended after a training session ($t = -4.42$, $d = 0.98$, $P < 0.001$) and a significant reduction after detraining ($t = 4.01$, $d = 0.81$, $P < 0.05$) returning to pre-training values ($t = -1.11$, $P > 0.05$). However, the CG showed no significant differences either between M1 and M2 ($t = 0.25$, $P > 0.05$) or between M2 and M3 ($t = 1.61$, $P > 0.05$).

Sprint performance

The L-P did not influence the V0, $F(2–26) = 1.49$, $P > 0.05$, $n^2_p = 0.103$. In the pairwise comparisons, no significant changes either in the EG ($t = -1.43$, $P > 0.05$) or the CG ($t = 0.47$, $P > 0.05$) were observed after training or detraining: EG ($t = -1.52$, $P > 0.05$), CG ($t = -1.71$, $P > 0.05$).

The Fh0 was not modified by the L-P, $F(2–26) = 0.158$, $P > 0.05$, $n^2_p = 0.012$. No significant changes, either in the EG ($t = 0.09$, $P > 0.05$) or in the CG ($t = 0.46$, $P > 0.05$), were observed between M1 and M2, or between M2 and M3: EG ($t = 0.45$, $P > 0.05$), CG ($t = -0.11$, $P > 0.05$).

The L-P did not vary the RFmax, $F(2–26) = 0.004$, $P > 0.05$, $n^2_p = 0.042$. No significant changes either in the EG ($t = -0.09$, $P > 0.05$) or the CG ($t = 1.33$, $P > 0.05$) were observed between M1 and M2, or between M2 and M3: EG ($t = 0.13$, $P > 0.05$), CG ($t = -0.54$, $P > 0.05$).

Along the same lines, neither did the L-P have an impact on the Pmax, $F(2–26) = 7.11$, $P > 0.05$, $n^2_p = 0.052$. No significant changes in the EG ($t = -0.97$, $P > 0.05$) or the CG ($t = 0.37$, $P > 0.05$) were observed after training or detraining: EG ($t = 0.55$, $P > 0.05$), CG ($t = -0.01$, $P > 0.05$).

Soreness

No significant effect on the soreness perceived was detected in the EG between M1 and M2 ($t = 0.69$, $P > 0.05$). The average of the soreness measurements reported in the 8 weeks stood at 1.42 ± 0.3 ($\bar{x} \pm S\bar{x}$) (▶ **Fig. 5**).

Discussion

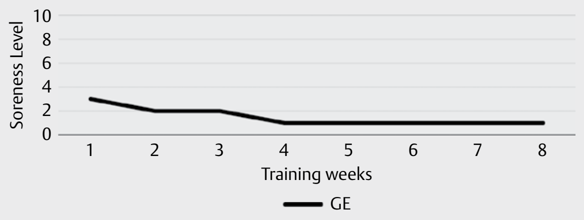
This study is the first to quantify the architectural adaptations, hamstring muscle flexibility and sprint performance derived from an Askling L-PROTOCOL [23, 32] involving 8 weeks of training and 4 weeks of subsequent detraining. The abovementioned authors showed that the L-P significantly reduced the time necessary before returning to sporting activity after HSI in comparison with a protocol based on more traditional exercises [23, 32]. The results obtained in our study would seem to show that the L-P does not have a significant impact on BFlh muscle architecture or on variables that influence sprint performance. Having said this, it does seem to have a significant impact on the flexibility of hamstring muscle structures, extending the range of motion for flexing the hip joint with the knee extended.

Muscle architecture is a factor to be taken into account in HSI; more specifically, the variable known as muscle fascicle length (FL). The presence of short BFlh fascicles increases the risk of HSI [12] and suffering such injuries reduces FL, increasing the risk of a relapse [16] , which becomes a negative feedback mechanism. Eccentric stimuli such as the NHE have shown their ability to lengthen the BFlh fascicle length [21, 22] and, therefore, act as a protective factor when confronted with HSI and recurrences [19, 20]. In

▶ **Table 3** Changes in EG and CG variables before (M1) and after (M2) the intervention and after the period of detraining (M3) (mean ± standard deviation).

	M1 (week 2)	**M2 (week 11)**	**M3 (week 15)**	**% Change M1-M2**	**% Change M2-M3**
EG					
BFlh architecture					
FL (cm)	8.79 ± 1.39	8.58 ± 1.63	8.86 ± 1.52	− 2.39	3.26
PA (°)	15.34 ± 2.87	15.31 ± 2.61	15.51 ± 1.87	− 0.19	1.31
MT (cm)	2.24 ± 0.15	2.34 ± 0.36	2.23 ± 0.14	4.46	− 4.70
Flexibility of hamstring muscles					
ROM (°)	69.64 ± 9.49	78.85 ± 9.21 *	71.42 ± 9.33#	13.22	− 9.42
Sprint performance					
V0 (m/s)	8.99 ± 0.69	9.49 ± 1.65	9.21 ± 1.51	5.56	− 2.95
Fh0 (N/kg)	4.94 ± 0.61	4.91 ± 0.91	4.83 ± 0.66	0.61	− 1.62
RFmax (%)	35 ± 3	35 ± 4	35 ± 4	0	0
Pmax (W/kg)	11.07 ± 1.79	11.41 ± 2.09	11.28 ± 1.94	3.07	− 1.14
CG					
BFlh architecture					
FL (cm)	8.76 ± 0.94	8.61 ± 1.16	8.78 ± 0.91	− 1.71	1.97
PA (°)	15.36 ± 2.02	16.27 ± 2.34	15.56 ± 1.59	5.92	− 4.36
MT (cm)	2.27 ± 0.22	2.28 ± 0.21	2.26 ± 0.18	0.44	− 0.88
Flexibility of hamstring muscles					
ROM (°)	73.14 ± 6.93	72.92 ± 8.24	71.57 ± 8.18	− 0.31	− 1.85
Sprint performance					
V0 (m/s)	9.48 ± 0.91	9.42 ± 1.17	9.80 ± 1.43	− 0.63	− 4.03
Fh0 (N/kg)	5.09 ± 0.69	5.03 ± 0.95	5.06 ± 0.96	− 1.18	0.59
RFmax (%)	35 ± 2	34 ± 4	35 ± 4	− 1	1
Pmax (W/kg)	11.23 ± 1.71	11.15 ± 2.08	11.25 ± 2.14	− 0.71	0.89

FL = fascicle length, PA = pennation angle, MT = muscle thicknes, ROM = hip bending range, V0 = theoretical maximum speed, Fh0 = horizontal force, RFmax = ratio of force application, Pmax = horizontal power. * $P<.001$ vs M1, #$P<.05$ vs M2.



▶ **Fig. 5** Mean weekly soreness measured using a numeric pain rating scale (1–10) at the beginning of each training session for GE.

our study, an 8-week L-P has not been shown to have an impact on BFlh muscle architecture (− 2.39 %, $P>0.05$) to the extent it causes changes to the FL. This result could be because, despite presenting a neuro-dynamic profile and a work pattern similar to that achieved during running [11] and the NHE [43], this circumstance occurs at a lower level of general activation [35] with a lesser eccentric impact that would not have the capability to cause such deep architectural changes. However, it is important to warn that the study was carried out with non-injured individuals and, therefore, we do not know how the L-P could affect previously injured and potentially more limited muscle fascicle architecture. This said, the L-P was able to stabilise the initial architectural characteristics after the training period and not reduce the FL in the way that other more concentric stimuli do [44]. This stabilisation of basic architectural conditions could be a characteristic that makes the L-P a good strategy to be maintained during the season in healthy individuals or those who have recovered from a previous HSI.

The L-P did not have a significant impact on sprint performance. The Fh0, highly relevant for short sprint accelerations, and the V0, crucial for long sprint accelerations and reaching a high sprint speed [40], remained stable between M1 and M2 (+ 0.61 % $P>0.05$ and + 5.56 $P>0.05$, respectively). Previously, other exercises associated with HSI, such as the NHE, which showed good results insofar as prevention and rehabilitation are concerned [19, 30], have been inconclusive on sprint performance. Positive effects were found on 10 m short sprint performance after 10 weeks of NHE protocol [29], but not on acceleration or long sprint > 30 m after a 4-week protocol [42]. It seems reasonable that eccentric training, in isolation, is not capable of improving sprinting on its own. This skill has a technical component and a complex neurodynamic pattern that influences performance and the type of slow eccentric contraction that occurs in the NHE or L-P would also not contribute to an improvement in maximal speed. This result is expected because these exercises were created to be applied in prevention and rehabilitation protocols, and not with the specific aim to improve sprint performance. Therefore, if the objective is to implement these exercises in daily training routines during season period, we should consider not only the positive effects on muscle structure, but also it would be vital to know if the use of these exercises could cause negative physical sensations (p.e. muscle soreness) or side-effects, affecting adherence to training.

For example, the NHE, which has been widely discussed by the scientific community and which does not seem to have a negative influence on sprinting, has shown little power of effective implementation in the planning of teams and athletes [31] despite its potential positive effects. Bahr et al. [31] studied the monitoring of the NHE programmes of 50 European professional football teams over 3 seasons (2012–2014), and their results showed that scarcely 6 % of such programmes were partially completed and only 10.7 % totally completed. Therefore, 83.3 % of the 150 NHE programmes studied by these authors were not completed. This reality might be brought about by the perceived muscular soreness and discomfort that a high-impact eccentric exercise such as the NHE causes in athletes and which makes its integration in daily training routines difficult [31]. Freeman et al.[42] observed no changes in the sprint performance of individuals subjected to a 4-week NHE protocol, but did observe a greater level of perceived muscular soreness (4.06 points on a scale of 10) than that shown in our results during the 8-week L-P (1.12 points). This is emphasised if we bear in mind that our study comprised 6 weekly L-P sessions, while the NHE in the study by Freeman et al. [42] comprised only 2, making it plausible to think that the nature of the L-P exercises generates a reduced sensation of pain in spite of their greater volume. The sensation of muscular pain has a subjective influence on the sportsperson and could be a factor that leads him/her to reject doing exercises such as the NHE continuously during a season [31]. This circumstance could constitute a positive value of the L-P if it is to be included as content in the warm-up phase of training sessions, given its limited influence on perceived pain and on sprint performance, both crucial variables for the quality of the content of the most important part of training and competition.

The L-P affected the hip flexion range of motion with knee extension positively (+ 13.22 % $P<0.001$), a joint pattern that influences sprint actions and the prevention of hamstring muscle injuries [34]. The results also indicate that after a 4-week detraining period, said variable is regressed (− 9.42 % $P<0.05$) returning to pre-training values. It seems that the stimuli generated by the L-P exercises are sufficient to produce an elongation in the hamstring muscles which, when they disappear, return to their initial state. We believe that, on its own, this circumstance could not explain the success of the L-P in HSI rehabilitation. But if to this finding we add the results observed by Severini et al. [35] in the neuro-mechanical profile of the L-P, we could be closer to understanding it. These authors point out that in the L-P the hamstring muscles are: a) contracted eccentrically at a work point similar to that in the thrust phases of running and sprinting; b) passively stretched (EX exercise) or contracted eccentrically and actively to stabilise the body (DV) and to resist hip flexion (GL); c) recruited in coactivation modules that can have different functions, whether related to conduction or movement stability. In this way, a plausible hypothesis would be that the L-P is capable of causing a chronic impact on hamstring muscle flexibility, but through dynamic eccentric exercises with neurodynamic patterns easily assimilated into running and sprinting techniques. Although they may not cause an eccentric impact sufficient to lengthen the muscle fascicles, this combination of improved flexibility, eccentric force at moderate intensity and dynamic executions relatable to running could be the combination to bring about their potential benefits in HSI.

There are limitations that must be considered in this research. Firstly, all of the participants were healthy, recreationally active males, and therefore it is unclear whether these interventions would bring about similar adaptations in a population of highly trained athletes. Having said this, the interventions by Askling et al. [23, 32] were carried out on elite athletes and had a positive impact on their rehabilitation. Secondly, the field of vision of the 2D ultrasound scanner used was not able to show a complete fascicle, meaning that an indirect estimation using a previously validated equation had to be used [38]. It should be taken into consideration that the evaluator (MFJ) has been shown to be reliable in previous studies [22] .

Perspective

The main practical contribution and novelty of these findings is to be found in the possibility of considering the true role that the L-P could play in sports training today. For practical purposes, we believe that the results obtained characterise the L-P conceived by Askling et al. [23, 32] as a protocol that: a) does not influence BFlh architecture and sprint performance; b) does not generate relevant muscular discomfort; c) improves hamstring muscle flexibility; d) shows a neuro-dynamic pattern easily assimilated into running [35], generating eccentric contractions and moderate muscle lengthening. These characteristics could be sufficiently relevant to evaluate whether or not they could be included regularly in athlete’s training programmes, especially considering that other exercises, such as the NHE, have failed in this regard. Although initially designed as a rehabilitation protocol, the results obtained might suggest that the L-P could be used as a preventative measure. This could be positive in maintaining the levels reached after applying a prior protocol based on content of a greater impact (NHE or isokinetic loading, for example) when the sportsperson returns to his/her habitual training or competition dynamic. Furthermore, given its characteristics, it could be applied in routines (warm-up) prior to training/competition, as it helps maintain FL benefits and improve hamstring muscle flexibility, affecting neither subsequent sprint performance nor the sportsperson’s perceived soreness. However, further studies will be necessary to validate these hypotheses.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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