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The objective of this study was to examine the effects of a neuromuscular training program combining eccentric hamstring muscle strength, plyometrics, and free/resisted sprinting exercises on knee extensor/flexor muscle strength, sprinting performance, and horizontal mechanical properties of sprint running in football (soccer) players. Sixty footballers were randomly assigned to an experimental group (EG) or a control group (CG). Twenty-seven players completed the EG and 24 players the CG. Both groups performed regular football training while the EG performed also a neuromuscular training during a 7-week period. The EG showed a small increases in concentric quadriceps strength (ES = 0.38/0.58), a moderate to large increase in concentric (ES = 0.70/0.74) and eccentric (ES = 0.66/0.87) hamstring strength, and a small improvement in 5-m sprint performance (ES = 0.32). By contrast, the CG presented lower magnitude changes in quadriceps (ES = 0.04/0.29) and hamstring (ES = 0.27/0.34) concentric muscle strength and no changes in hamstring eccentric muscle strength (ES = –0.02/0.11). Thus, in contrast to the CG (ES = –0.27/0.14), the EG showed an almost certain increase in the hamstring/quadriceps strength functional ratio (ES = 0.32/0.75). Moreover, the CG showed small magnitude impairments in sprinting performance (ES = –0.35/–0.11). Horizontal mechanical properties of sprint running remained typically unchanged in both groups. These results indicate that a neuromuscular training program can induce positive hamstring strength and maintain sprinting performance, which might help in preventing hamstring strains in football players.

Acute hamstring muscle tears represent 12% to 16% of the total amount of injuries in football (soccer) injuries (Woods et al., 2004; Ekstrand et al., 2011). A professional male football team with 25 players could be expected to suffer about five hamstring injuries per season with an incidence of 0.5 to 1.5 injuries per 1000 h of football exposure (match and training; Ekstrand et al., 2011). In addition to the high incidence, a common problem concerning this injury is the high risk of recurrence (12–31%) and its consequent devastating effects both at economical and performance level for the club and player (Woods et al., 2004).

The main functions of the hamstring muscles are hip extension and knee flexion. However, the requirements of the hamstrings in terms of force, velocity, and power are limited during walking and jogging compared with during sprinting (Novacheck, 1998). The hamstring muscle group acts eccentrically both during the late swing and terminal stance phases of the running cycle (Thelen et al., 2005; Yu et al., 2008; Schache et al., 2011). Kinetic and EMG studies reveal that the hamstrings are most active and develop the greatest torques at the hip and knee during late swing through to the midstance phase of running (Mann & Sprague, 1980; Thelen et al., 2005; Schache et al., 2013). The majority of hamstring injuries in football occur while players are running or sprinting (Woods et al., 2004). Whether the injury occurs during late swing or stance phase of the sprint, where the posterior thigh muscles generate tension while lengthening (eccentric contraction) to decelerate knee extension, still remains controversial (Thelen et al., 2005; Yu et al., 2008; Schache et al., 2013). Nevertheless, increasing the eccentric strength of the hamstring muscles, performed by lengthening the hamstring muscle complex while it is loaded and contracting, has been proposed as a method to prevent hamstring injuries (Askling et al., 2003; Arnason et al., 2008; Petersen et al., 2011).

In addition to its potential role in preventing hamstring muscle strains in football, posterior thigh (e.g., hamstrings) muscle strength is believed to be important for sprinting performance in football (Askling et al., 2003; Bračič et al., 2011; Lockie et al., 2012b). In this regard, the acceleration of the athlete's center of mass during sprint running is determined by body mass and three external forces acting on the body: ground reaction force (GRF), gravitational force, and air/wind resistance (Hunter et al., 2005). The only modifiable factor, which can potentially impact sprint acceleration performance, is the GRF. During the stance phase, posterior thigh bi-articular muscles act mainly as hip extensors to (a) push the ground backwards and thus counteract the knee torque caused by GRF, and (b) control the direction of external forces by producing a force that is directed horizontally but backwards, causing the body to propel forwards (Jacobs & van Ingen Schenau, 1992; Jacobs et al., 1996; Belli et al., 2002). The significant increase in the electromyography activity of the biceps femoris muscle with increasing running speed at foot-strike (Kyrolainen et al., 2001; Belli et al., 2002) together with a recent finding showing that horizontal maximum theoretical force and power appear impaired after return to sport from a hamstring injury in football players, could indicate that the hamstrings make a significant contribution to forward propulsion (Mendiguchia et al., 2014). Given the fact that high-speed running actions such as sprints are common in many match-winning actions such as win possession of the ball, pass a defending players, or gain position to score a goal (Faude et al., 2012), the development of posterior thigh muscle strength is believed to be important in order to improve sprint performance (Askling et al., 2003; Bračič et al., 2011; Lockie et al., 2012b).

Previous studies have reported the efficacy of different training modalities such as plyometrics (de Villarreal et al., 2008; Markovic & Mikulic, 2010) and free and/or resisted sprinting (Spinks et al., 2007; Harrison & Bourke, 2009; Lockie et al., 2012a) to improve sprinting performance in soccer players and other team sport athletes. Among other benefits, plyometrics training has been shown to improve both hamstring and plantar flexor muscles strength (both of them forward acceleration contributors; Markovic & Mikulic, 2010; Tsang & DiPasquale, 2011) and resemble the muscle contraction speed that most closely approximates muscle contraction speeds in the acceleration phase of the sprinting (Markovic & Mikulic, 2010). Improvements in acceleration after free and/or resisted sprint training appear to be primarily related to increases in horizontal and reactive power output, allowing athletes to apply strength more efficiently during ground contacts (Lockie et al., 2012a). Despite, all those training methods have been reported to work when applied in isolation; soccer teams and players typically perform them concurrently. However, no research has to date examined the efficiency of a simple, multicomponent, field-based training intervention designed to increase posterior thigh (hamstring) muscles strength considering and integrating both injury prevention and performance enhancement aspects.

Accordingly, the aim of this study was to examine the effects of 7 weeks of combined eccentric hamstring strength, forward-oriented plyometrics, and sprint training in addition to regular football training on knee joint muscles strength, sprinting performance, and horizontal mechanical properties of sprint running.

Material and methods

Subjects

A total of 12 amateur male football teams from the same geographic area and competitive level were contacted and informed about the project via email. Of those invited, three teams did not respond to repeated requests. Of the remaining nine teams, 60 football players (6.6 ± 3.8 per team) were voluntarily recruited and randomly assigned to either an experimental group (EG) or a control group (CG). To reduce potential confounding, a match-pair design was used in which athletes were matched depending on their position (i.e., defender, midfield, and forward) and playing status (i.e., starting or substitute player). After this stratification, 31 football players constituted the EG (22.2 ± 4.5 years; 70.7 ± 9.0 kg; 174.6 ± 6.1 cm), whereas another 29 athletes comprised the CG (21.9 ± 2.9 years; 71.4 ± 7.0 kg; 176.9 ± 5.8 cm). Inclusion criteria for both groups were (a) to be older than 18 years; (b) to have a competitive and consecutive experience in football at least 3 years priors to measurements; and (c) to start the preseason at the scheduled time. Exclusion criteria for both groups included (a) to be involved in any additional strength training program; (b) to present a history of hip, knee, thigh, or lumbopelvic injury in the past 3 years that required intervention by a health professional; and (3) to suffer a neurological, cardiorespiratory or systemic disorder (Sole et al., 2011). Five football players (two from CG and three from EG) were dropped from the study because of personal reasons or moving to another club. Another three players in the CG could not complete the minimum training (70%) and testing sessions because of a piriformis syndrome, fifth metatarsal fracture, and shoulder injury, respectively. One player in the EG suffered an anterior cruciate ligament tear. After these exclusions, 27 subjects constituted the EG (22.7 ± 4.8 years; 71.6 ± 8.7 kg; 175.2 ± 6.3 cm) and 24 players the CG (21.8 ± 2.5 years; 71.0 ± 7.7 kg; 176.9 ± 6.3 cm). All players trained three times per week during 90 min and played one official match at the weekend. Additionally, the EG performed a neuromuscular training program including eccentric, plyometric, and acceleration exercises two times per week during 7 weeks.

All subjects were informed of potential risks associated with the experimental procedures before giving their written informed consent to participate, and ethics approval was granted by the Catholic University of San Antonio (Spain) human research ethics committee, which conforms to the ethical standards established by the Declaration of Helsinki.

Assessments

The football players involved in this study were assessed before (pre-test) and after (post-test) the 7-week training period. Previously to pre- and post-test, subjects were requested not to train or exercise vigorously during at least 2 days. Both pre- and post-test consisted of two measurement sessions carried out on two different days. On day 1, sprinting performance was assessed. On day 2, knee extension and flexion isokinetic strength was assessment. Both testing sessions (i.e., sprinting and strength) was separated by at least 24 h.

Sprint running test

A standardized warm-up, which comprised 5 min of low-pace (~ 10 km/h) running, followed by 3 min of lower limb muscle stretching, 5 min of sprint-specific drills, and three progressive 6-s sprints separated by 2 min of passive rest, was carried out before the sprint running test. Subjects were then allowed 5 min of free cool-down before performing two 50-m maximal sprints from a standing start on an artificial turf field. Both sprints were separated by 6 min of passive rest. The same investigator (E. M. R.) supervised all tests. Players wore their habitual football boots and tests were performed at the same time of the day (always before of their normal football training). Pre- and post-tests were performed under similar environmental conditions of temperature (20.2 ± 3.2 °C pre-test vs 17.1 ± 4.7 °C post-test), humidity (56.9 ± 27.4% pre-test vs 40.6 ± 8.2% post-test) and wind (3.6 ± 2.1 km/h pre-test vs 2.6 ± 2.7 km/h post-test) according to anemometer PCE-AM 82 (PCE Ibérica, Tobarra, Albacete, Spain).

Each sprint was measured by means of a Radar Stalker ATS SystemTM (Radar Sales, Minneapolis, Minnesota, USA), which was placed on a tripod 10 meters behind the subjects at a height of 1 meter corresponding approximately to the height of subjects' center of mass. This device measures the forward sprinting velocity of the subject at a sampling rate of 33.25 Hz, and has been previously validated in human sprint running experiments (di Prampero et al., 2005; Morin et al., 2006). From these measurements, speed-time curves were plotted (Jacobs et al., 1996; Cormie et al., 2011), and maximal running speed as well as 5 and 20 m mean velocity was obtained. Additionally, horizontal external power (Pmax) and its respective velocity (V0) and force (F0) components were obtained using a recently validated computational method from speed-time data measured during sprinting (see Mendiguchia et al., 2014 and Samozino et al., 2013 for more details). In particular, since mechanical power is the product of force and velocity, the slope of the linear F–V relationship (Morin et al., 2011) may indicate the relative importance of force and velocity qualities in determining the maximal power output of each subject. These individual F–V relationships describe the changes in external horizontal force generation with increasing running velocity and may be summarized through their two theoretical extrema: the theoretical maximal horizontal force the legs could produce over one contact phase at null velocity (F0), and the theoretical maximal velocity the legs could produce during the same phase under zero load (V0; Samozino et al., 2012, 2013).

Isokinetic strength test

Prior to the isokinetic strength test, subjects performed a standardized warm-up consisting of 10 min of stationary cycling at low resistance (75 to 100 W) and moderate speed (Croisier et al., 2008), followed by active and ballistic lower limb muscle stretching. Immediately after the warm-up, players were seated on the isokinetic dynamometer Biodex System 3 (Biodex Medical System, Shirley, New York, USA) with approximately 90° of coxofemoral flexion and the body firmly stabilized by several straps around the thigh, waist, and chest to avoid unwanted movements. In addition, the players were requested to grip side handles to help stabilize the upper body (Brughelli et al., 2010). The axis of rotation of the dynamometer was visually aligned with the center of the lateral epicondyle of the femur, and the lower leg was attached to the lever arm of the dynamometer 2 centimeters proximal to the lateral malleolus. The range of knee motion was fixed at 90° of flexion from the active maximum extension.

Before the actual test, players were asked to perform six concentric and three eccentric submaximal repetitions at increasing intensities. Afterward, players were requested to perform six maximum concentric contractions of the knee extensors and flexors, followed by other six knee flexors maximum eccentric contractions all at the angular velocity of 60°s. A single clinician (E. M. R.) conducted all of the isokinetic testing. 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. The order of leg testing was randomized. Concentric strength was always assessed before eccentric strength. In the same way, knee extension was tested first followed by knee flexion. During the testing, all players received strong verbal encouragement, but no visual feedback was given. A 60-s recovery period was allowed between contractions, and a 180-s rest period between legs (Gioftsidou et al., 2008).

This isokinetic dynamometer has been shown to have good within- and between-session reliability and validity at angular velocity of 60° s (Drouin et al., 2004). From these measurements, the concentric quadriceps peak torque (Con PT Q), concentric and eccentric hamstring peak torque (Con PT H and Ecc PT H, respectively), and conventional and functional ratio (Con Ratio H/Q and Ratio Hecc/Qcon, respectively) of both legs were obtained.

Neuromuscular training intervention

The training program was carried out during the first half of the Spanish league championship. This program comprised 14 sessions, which were performed twice per week for a 7-week period. Each session lasted about 30–35 min and was performed in a non-fatigued state (i.e. before the regular football training session; Askling et al., 2003), after a standardized warm-up (identical to the warm-up used in the sprint running test – see above). In the first session of each week, players in the EG performed mainly eccentric strength and plyometric exercises, whereas in the second session of the week, players performed eccentric strength and acceleration exercises (Table 1). A minimum of 48 h separated each training session. All training sessions were supervised by different researchers, physiotherapists or coaches.

Statistical methods

Data in the text are presented as means ± SD. Data were analyzed for practical significance using magnitude-based inferences (Hopkins et al., 2009). We used this qualitative approach because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to athletic performance than any statistically significant effect (Hopkins et al., 2009). Between-group standardized differences or Cohen effect sizes (d; 90% confidence limits, CL) in the selected performance variables were calculated using the pre-training standard deviations. Effects were evaluated for practical significance by pre-specifying 0.2 between-subject SDs as the smallest worthwhile difference (SWD; Hopkins et al., 2009). Threshold values for d statistics were < 0.20, < 0.60, < 1.2, and > 2.0 for trivial, small, moderate, large, and very large, respectively (Hopkins et al., 2009). Probabilities were also calculated to establish whether the true (unknown) differences were lower, similar or higher (i.e., substantial) than the SWD. Chances of higher or lower differences were evaluated qualitatively as follows: ≤ 1%, almost certainly not; > 1–5%, very unlikely; > 5–25%, unlikely; > 25–75%, possible; > 75–95%, likely; > 95–99%, very likely; > 99%, almost certain (Hopkins et al., 2009). If the chance of both higher and lower values was > 5%, the true difference was assessed as unclear (Hopkins et al., 2009). Otherwise, we interpreted that change as the observed chance.

Table 1. Training contents for the neuromuscular training group

	Weeks 1	2	3	4	5	6	7
Eccentric exercises	First training session of the week						
	Nordic hamstring 2 sets × 5 reps Forward lunge 2 × 6	Forward lunge 2 × 8 Single-leg bridge 2 × 8 Double-leg hip thrust (50% BW) 2 × 8	Double-leg deadlift (15 kg) 2 x 8 Forward lunge (10% BW) 2 × 6 Double-leg hip thrust (60% BW) 2 × 8	Double-leg hip thrust (60% BW) 3 × 4 Bridge walkout 2 × 7	Forward lunge (15% BW) 2 × 6 Nordic hamstring 3 × 4 Double-leg hip thrust (60% BW) 2 × 8	Double-leg hip thrust (70% BW) 2 × 8 Loaded lunge box drop 2 × 6 Bridge walkout 2 × 6	Double-leg hip thrust (70% BW) 3 × 6 Nordic hamstring 2 × 6
	Second training session of the week						
	Double-leg deadlift (10 kg) 2 × 5 Eccentric box drop 2 × 4	Single-leg deadlift 2 × 6 Bridge walkout 2 × 6	Nordic hamstring 2 × 8 Single-leg deadlift 2 × 6	Eccentric box drop 3 × 5 Lunge box drop 2 × 6	Double-leg hip thrust (70% BW) 3 × 5 Double-leg deadlift (20 kg) 3 × 6	Single-leg deadlift (7 kg) 2 × 8 Forward lunge (15% BW) 2 × 6	Single-leg deadlift (5 kg) 3 × 5 Forward lunge (15% BW) 2 × 6
Plyometric exercises	First training session of the week						
	Broad jump 2 × 6 Hopscotch (10 m) 2 × 3	Broad jump (5 kg) 2 × 6 Double-leg forward box jump (60 cm) 2 × 8 Alternate leg bounding (20 m) 3 × 3	Double-leg hurdle jumps (50 cm) 3 × 3 Hopscotch (15 m) 1 × 4 Single-leg forward box hop (40 cm) 2 × 5	Single-leg hurdle hops (50 cm) 2 × 3 Broad jump (5 kg) 2 × 8 Long strides (25 m) 2 × 6	Single-leg 5 forward hop 2 × 4 Triple broad jump (5 kg) 2 × 3 Alternate leg bounding (20 m) 2 × 4	Long strides (half field) 2 × 6 Lateral double-legs drop jump from 40 cm to horizontal double-leg jump 2 × 5	Alternate two left leg hops + two right leg hops + double-legs landing 2 × 6 Lateral single-leg drop jump from 40 cm to horizontal single-leg jump 2 × 6 Broad jump (5 kg) 1 × 6
Acceleration exercises	Second training session of the week						
	Wall acceleration drill (two steps) 3 × 5 Free sprint (10 m) 2 × 5	Wall acceleration drill (two steps) 3 × 6 Free sprint (10 m) 2 × 7 Free sprint (20 m) 1 × 4	Wall acceleration drill (four steps) 2 × 6 Free sprint (5 m) 2 × 4 Free sprint (10 m) 1 × 2 Free sprint (15 m) 1 × 2	Wall acceleration drill (four steps) 2 × 7 10-m weighted sled towing (15% BW) + 10-m free sprint 2 × 2 Free sprint (15 m) 1 × 2	Wall acceleration drill (four steps) 2 × 8 15-m weighted sled towing (15% BW) + 10-m free sprint 2 × 2 Free sprint (10 m) 1 × 2	Wall acceleration drill (four steps) 2 × 6 15-m weighted sled towing (15% BW) + 10-m free sprint 2 × 3 Free sprint (5 m) 2 × 4	Wall acceleration drill (two steps) 3 × 5 10-m weighted sled towing (15% BW) + 10-m free sprint 2 × 2 Free sprint (10 m) 1 × 4

Table 2. Anthropometric, quadriceps and hamstring strength, sprinting performance, and mechanical variables (mean ± SD) for experimental group and the changes (with 90% confident limits) and probabilistic inferences about the true standardized magnitude in the means between pre- and post-test

Variables	Experimental group				Qualitative assessment
	Pre-test	Post-test	Changes (% ± 90% CL)	Standardized differences (ES ± 90% CL)	
Body mass (kg)	70.8 ± 9.0	71.6 ± 8.8	+0.8 (1.4;0.2)	+0.06 (0.11;0.01)	(0/100/0) Almost certainly trivial changes
Height (cm)	174.6 ± 6.2	175.2 ± 6.4	+0.1 (0.0;0.3)	+0.03 (−0.01;0.07)	(0/100/0) Almost certainly trivial changes
Con D PT Q (N/kg)	276.5 ± 32.8	286.1 ± 28.5	+4.4 (1.1;7.7)	+0.38 (0.10;0.66)	(0/14/86) Likely increase
Con D PT H (N/kg)	140.4 ± 28.8	158.8 ± 21.9	+14.8 (9.4;20.5)	+0.74 (0.49;0.98)	(0/0/100) Almost certainly increase
Con D Ratio H/Q	0.51 ± 0.08	0.56 ± 0.08	+10.0 (3.7;16.6)	+0.59 (0.25;0.93)	(0/3/97) Very likely increase
Con ND PT Q (N/kg)	265.0 ± 34.1	283.5 ± 38.8	+8.1 (5.4;10.9)	+0.58 (0.38;0.77)	(0/0/100) Almost certainly increase
Con ND PT H (N/kg)	134.8 ± 25.9	151.1 ± 21.0	+13.7 (7.3;20.4)	+0.70 (0.40;1.00)	(0/0/100) Almost certainly increase
Con ND Ratio H/Q	0.51 ± 0.08	0.54 ± 0.07	+5.1 (−1.3;12.1)	+0.30 (−0.07;0.67)	(1/31/68) Possibly increase
Ecc D PT H (N/kg)	246.2 ± 44.0	288.5 ± 41.6	+15.2 (12.0;18.5)	+0.87 (0.69;1.05)	(0/0/100) Almost certainly increase
Ecc ND PT H (N/kg)	237.2 ± 45.4	268.5 ± 43.5	+13.0 (10.1;15.9)	+0.66 (0.53;0.79)	(0/0/100) Almost certainly increase
D Ratio Hecc/Qcon	0.89 ± 0.13	1.01 ± 0.11	+10.3 (5.9;15.0)	+0.75 (0.45;1.06)	(0/0/100) Almost certainly increase
ND Ratio Hecc/Qcon	0.89 ± 0.13	0.95 ± 0.12	+4.5 (1.0;8.1)	+0.32 (0.08;0.56)	(0/20/80) Likely increase
V0 (m/s)	8.5 ± 0.5	8.5 ± 0.5	− 0.3 (−1.5;0.9)	− 0.05 (−0.26;0.16)	(3/86/11) Likely trivial changes
F0 (N/kg)	7.1 ± 0.7	7.2 ± 0.7	+0.8 (−2.9;4.6)	+0.08 (−0.28;0.45)	(10/60/30) Unclear
Pmax (W/kg)	14.9 ± 1.5	15.0 ± 1.5	+0.5 (−2.8;3.8)	+0.05 (−0.26;0.37)	(9/69/22) Unclear
V5m (km/h)	20.6 ± 0.9	20.8 ± 1.0	+1.6 (−0.3;3.4)	+0.32 (−0.05;0.69)	(1/28/71) Possibly increase
V20m (km/h)	28.1 ± 1.2	28.0 ± 1.3	− 0.6 (−1.6;0.5)	− 0.13 (−0.36;0.10)	(30/69/1) Possibly trivial changes
Top speed (km/h)	30.3 ± 1.3	30.2 ± 1.6	− 0.4 (−1.5;0.7)	− 0.07 (−0.30;0.15)	(17/80/3) Likely trivial changes

− values, worse performance in the post-test.
+ values, better performance in the post-test.

Results

Within-group training responses

The EG showed a small increase in concentric quadriceps strength, with a moderate increase in concentric and eccentric hamstring strength (Table 2). This induced a substantial increase in the conventional and, more importantly, in the functional hamstring/quadriceps ratio (Table 2). Trivial and unclear changes were observed in most of the sprint mechanical variables analyzed. Only sprint performance at 5 m showed a small but substantial improvement after the training intervention (Table 2). By contrast, the CG showed small magnitude changes in concentric quadriceps and hamstring strength and trivial/unclear changes in most of the other analyzed variables (Table 3).

Between-groups comparisons

No substantial differences were found in age, height, and body mass between EG and CG. The EG showed an almost certain increase in both the concentric and the eccentric knee flexion strength of the dominant leg (Fig. 1) in comparison with control group. Similarly, the EG presented an almost certain increase in the functional hamstring/quadriceps ratio, with small changes in the conventional hamstring/quadriceps ratio in relation with control group. With respect to mechanical variables and sprinting performance, the experimental group presented only a possibly better (moderate magnitude differences) 5-m sprint performance than the control group.

Discussion

The aim of the present study was to examine the effects of a 7-week simple, field-based neuromuscular training program, that combined posterior thigh eccentric-biased muscle strength, horizontal-focused lower limb plyometrics, and sprint training drills, in addition to regular football training on knee extension/flexion strength, sprinting performance, and horizontal mechanical properties of sprint running. The main findings of the present study were (a) the addition of two weekly sessions of neuromuscular training induced substantial improvements in eccentric and concentric hamstring strength, with lower magnitude effects on quadriceps muscles strength resulting in a increased functional H/Q ratio; (b) apart from a small, but substan-

Table 3. Anthropometric, quadriceps and hamstring strength, sprinting performance and mechanical variables (mean ± SD) for control group and the standardized changes (with 90% confident limits) and probabilistic inferences about the true standardized magnitude in the means between pre- and post-test.

Variables	Control group				Qualitative assessment
	Pre-test	Post-test	Changes (% ± 90% CL)	Standardized differences (ES ± 90% CL)	
Body mass (kg)	71.5 ± 7.1	71.1 ± 7.7	– 0.7 (–1.2;–0.1)	– 0.06 (–0.11;–0.01)	(0/100/0) Almost certainly trivial changes
Height (cm)	177.0 ± 5.9	176.9 ± 6.3	+0.0 (–0.1;0.2)	+0.01 (–0.03;0.06)	(0/100/0) Almost certainly trivial changes
Con D PT Q (N/kg)	276.7 ± 37.6	286.4 ± 34.8	+4.1 (1.4;6.8)	+0.29 (0.10;0.49)	(80/20/0) Likely increase
Con D PT H (N/kg)	140.0 ± 34.1	147.2 ± 21.4	+8.9 (1.1;17.2)	+0.34 (0.06;0.63)	(80/20/0) Likely increase
Con D Ratio H/Q	0.51 ± 0.11	0.52 ± 0.06	+4.6 (–3.6;13.5)	+0.14 (–0.22;0.51)	(40/54/6) Unclear changes
Con ND PT Q (N/kg)	277.8 ± 40.3	280.9 ± 31.5	+0.6 (–2.9;4.3)	+0.04 (–0.22;0.29)	(6/80/14) Likely trivial changes
Con ND PT H (N/kg)	131.7 ± 31.8	138.3 ± 23.4	+7.3 (1.5;13.4)	+0.27 (0.04;0.50)	(70/30/0) Possibly increase
Con ND Ratio H/Q	0.47 ± 0.09	0.49 ± 0.07	+6.7 (0.8;12.8)	+0.29 (0.01;0.58)	(71/29/0) Possibly increase
Ecc D PT H (N/kg)	254.1 ± 42.6	250.7 ± 44.4	– 0.6 (–5.9;5.0)	– 0.02 (–0.30;0.26)	(10/76/14) Possibly trivial changes
Ecc ND PT H (N/kg)	238.6 ± 48.5	243.0 ± 46.6	+2.7 (–1.6;7.2)	+0.11 (–0.09;0.30)	(21/78/1) Likely trivial changes
D Ratio Hecc/Qcon	0.92 ± 0.13	0.88 ± 0.15	– 4.5 (–9.8;1.1)	– 0.27 (–0.60;0.06)	(1/35/64) Possibly decrease
ND Ratio Hecc/Qcon	0.86 ± 0.14	0.87 ± 0.14	+2.1 (–2.4;6.8)	+0.14 (–0.13;0.40)	(34/64/2) Possibly trivial changes
V0 (m/s)	8.7 ± 0.4	8.6 ± 0.4	– 1.3 (–2.8;0.2)	– 0.30 (–0.64;0.04)	(1/30/69) Possibly decrease
F0 (N/kg)	7.1 ± 0.7	7.1 ± 0.8	– 0.1 (–4.9;4.9)	+0.00 (–0.45;0.45)	(23/54/23) Unclear changes
Pmax (W/kg)	15.3 ± 1.6	15.0 ± 1.5	– 1.4 (–5.2;2.5)	– 0.14 (–0.50;0.23)	(6/55/39) Unclear changes
V5m (km/h)	20.9 ± 1.3	20.4 ± 1.4	– 2.1 (–4.7;0.6)	– 0.32 (–0.73;0.08)	(1/29/70) Possibly decrease
V20m (km/h)	28.7 ± 1.1	28.5 ± 1.0	– 0.4 (–1.6;0.9)	– 0.11 (–0.45;0.23)	(7/61/32) Unclear changes
Top speed (km/h)	30.8 ± 1.2	30.3 ± 1.1	– 1.4 (–2.3;–0.4)	– 0.35 (–0.59;–0.11)	(0/14/86) Likely decrease

– values, worse performance in the post-test.
+ values, better performance in the post-test.

tial, improvement in 5-m sprinting performance, the neuromuscular training program did not modify sprint performance or mechanical properties in sprint running; and (c) low magnitude changes (either improvements or decrements) or no changes were observed in the parameters studied after 7 weeks of regular football practice (training and competition) during the same period of time.

The present study is, to the authors' knowledge, the first that integrates a commonly used injury prevention-oriented hamstring strength exercises with a training program targeting sprinting performance (i.e., acceleration drills and horizontal plyometrics) in an ecological context. The players, subjected to the neuromuscular training intervention, improved their ability to develop eccentric hamstring torque with a concurrent lower magnitude increase in quadriceps torque, which in turn resulted in a substantial improvement in the functional H/Q ratio (Table 2). The improvement in eccentric hamstring muscle strength in the present study (~15%) is comparable to previous studies with football players where increased eccentric hamstring peak toque at 60° s between 11% and 21% was observed after hamstring-emphasized resistance training (Askling et al., 2003; Mjolsnes et al., 2004). An interesting finding of the present study was that, as training induced twofold to threefold lower increases in quadriceps peak torque than in hamstring peak torque, the functional H/Q ratio substantially increased from 0.89 to 1.01. Similar to the current study, Mjolsnes et al. (2004) showed a significant increase in the functional H/Q ratio in experienced male football players from 0.89 to 0.98 with 10 weeks of eccentric hamstring training. The increases in the functional H/Q ratio reported in previous studies (Askling et al., 2003; Mjolsnes et al., 2004), which have only employed posterior thigh eccentric strength exercises, were similar to the observed in the present study that additionally incorporated horizontal plyometrics and sprinting drills. It can therefore be speculated that the increase in the hamstring eccentric strength, and in turn, the functional H/Q ratio observed in the present study, was mainly due to the posterior thigh muscle focuses eccentric strength exercises (e.g., Nordic hamstring, deadlift, lunges). Since the majority of hamstring injuries in football appear to occur when the hamstring muscles generate tension while lengthening and that football players classified as having a low functional H/Q ratio in the preseason have been reported to be more likely to sustain a hamstring muscle strain-type injury (Croisier et al., 2008), implementation of these type of training intervention appears to be of interest.

Previous studies investigating free and/or resisted sprint training (Spinks et al., 2007; Harrison & Bourke, 2009; Lockie et al., 2012a) or plyometrics (de Villarreal

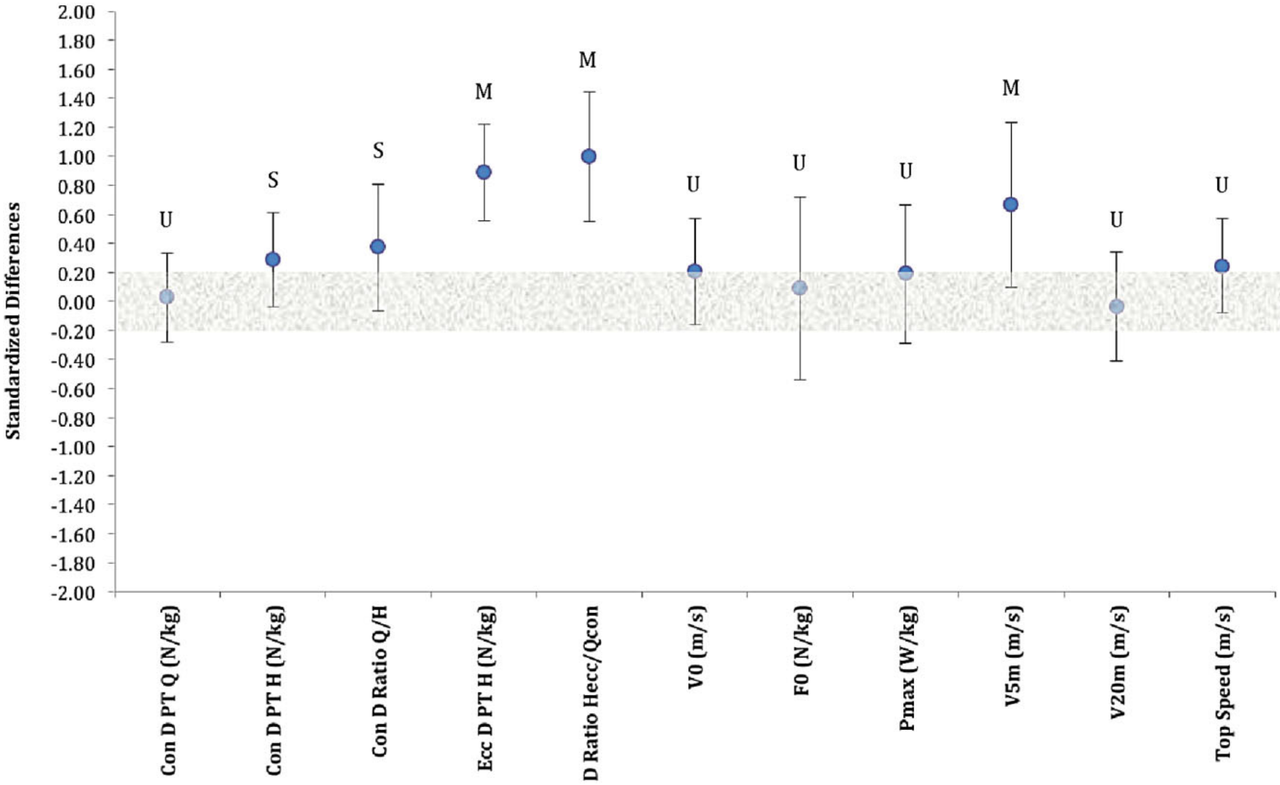

Fig. 1. Efficiency of the neuromuscular training program compared with the control group to improve dominant limb quadriceps concentric peak torque (Con D PT Q), dominant limb hamstring concentric peak torque (Con D PT H), dominant limb conventional ratio (Con D Ratio Q/H), dominant limb hamstring eccentric peak torque (Ecc D PT H), dominant limb functional ratio (D Ratio Hecc/Qcon), theoretical maximal velocity (V0), theoretical maximal horizontal force (F0), maximal horizontal external power (Pmax), velocity at 5 m (V5m), velocity at 20 m (V20m) and top speed (bars indicate uncertainty in the true mean standardized changes with 90% confident intervals). Trivial areas were calculated from the smallest worthwhile change (see Methods). Positive values favor the neuromuscular training group and negative values the control group. Letter "S" and "M" indicate small and moderate standardized differences vs the control group, respectively. Letter "U" indicate unclear differences vs the control group (see Methods).

et al., 2008; Markovic & Mikulic, 2010) training protocols have reported beneficial effects on sprint performance and several kinetics and kinematics parameters in team sport athletes. Present findings show that a posterior thigh strength program combined with both horizontal plyometrics and sprint (free and resisted) induced only a modest improvement in 5-m sprint performance compared with football practice alone. Moreover, the present training program did not induce a substantial change in horizontal mechanical properties (i.e., V0, F0, and Pmax) of sprint running (Table 2). It was somehow surprising to observe a change in 5-m sprint performance without a concomitant increase in horizontal mechanical properties because it has been suggested that F0 is a key variable in the acceleration phase (Morin et al., 2011). Thus, rather than via enhancements in horizontal force production (i.e., total amount of force players were able to produce), the observed 5-m sprint improvements in the present study might be related to changes in the way players applied force onto the ground (i.e., technical ability; Morin et al., 2011; Kawamori et al., 2013). The only modest improvements in acceleration (i.e., 5-m sprinting time), despite the substantial posterior chain muscles strength gains reported in the EG, might also suggest that other muscles such as the ankle plantar flexors, whose mechanical properties and strength increase after plyometric training (Markovic & Mikulic, 2010), are likely to be more important for accelerating the body's center of mass in the forward direction when running (Hamner & Delp, 2013). Despite that hamstring muscle activation and force requirements increase with faster running speeds (Belli et al., 2002; Schache et al., 2011), the substantial hamstring concentric and eccentric strength gains observed in the present study did not transfer into substantial changes in longer distances (i.e., 20-m and top speed) sprinting performance. Prioritization of the horizontal component over the vertical one in the training program may explain, at least partly, the unchanged performance in both 20-m sprint performance and top speed. This is partly supported by recent findings showing a positive link between the ability to apply high amounts of vertical force per unit of body mass and fast top speed (Weyand et al., 2010; Morin et al., 2011). Nevertheless, these findings question the idea that posterior chain muscle strengthening *per se* translates into an improvement of a complex action as maximal sprinting speed where theoretically hamstring muscles are heavily taxed (Askling et al., 2003).

Another interesting finding of the present study is that football practice alone during 7 weeks induced small, but substantial, changes in both quadriceps and hamstring muscles concentric strength (Table 3). However, eccentric hamstring muscle strength remained unchanged, which resulted in a substantial reduction of the functional H/Q (Table 3). It is believed that football can result in underdeveloped hamstring muscles strength compared with quadriceps muscles strength (Atkinson & Batterham, 2012). For example, Tourny-Chollet et al. (2000) reported lower functional H/Q ratios in experienced male football players (0.8 at 60° s and 0.88 at 120° s) than sedentary men (0.93 at 60° s and 1.03 at 120° s). In addition, a recently published meta-analysis showed increased quadriceps torque as a risk factor to posterior thigh muscles injury (Freckleton & Pizzari, 2013). Therefore, from an injury prevention perspective, the implementation of training programs aiming to increase the functional H/Q via enhanced hamstring muscle strength, similar to the reported in the present study, might prove valuable in such athlete's cohort.

Football training alone induced small, negative changes in sprinting performance while horizontal mechanical properties remained typically unchanged (Table 3). These results, in combination with the modest improvements in 5 m and unchanged 20 m and top speed performances observed in the EG suggests that the neuromuscular program employed in the present study can be effective in maintaining sprinting performance in football players (Fig. 1).

When interpreting the current findings, a number of limitations should be considered. Our population consisted of amateur, semiprofessional male football players. The generalization to other cohorts of players is not known. Some of the improvements observed in the isokinetic testing might have been due to the learning effect. However, as learning effect would have affected both groups equally, the observed between-group differences in several isokinetic strength parameters post-training support the impact of the neuromuscular training performed by the experimental group.

Perspectives

Based on the present results, 7 weeks of hamstring-emphasized neuromuscular training combined with football training appear to be effective in improving concentric and specifically eccentric hamstring muscles strength compared with football training alone. In addition, greater hamstring compared with quadriceps strength improvement resulted in an increase in both the conventional and functional ratio, which may be advantageous to prevent or rehabilitate hamstring muscle strains. Sprinting performance was typically maintained, with a small improvement observed in 5-m sprinting speed, in the experimental group while the football training group showed some small magnitude reductions in most of the sprinting speed parameters analyzed. From a practical point of view, the advantage of the intervention program is that it integrates a commonly used injury prevention-oriented hamstring strength exercises with a training program targeting sprinting performance (i.e., acceleration drills and horizontal plyometrics) in an ecological and real football team context.

Key words: Hamstring strength, sprint biomechanics, football, soccer, isokinetic.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Video S1. 2-LHops 2-RHops to Doub.mp4

Video S2. Doub to Doub.mp4

Video S3. Sing to Sing.mp4