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Effects of in-season enhanced negative work-based vs traditional weight training on change of direction and hamstrings-to-quadriceps ratio in soccer players

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ABSTRACT: The present study investigated the effects of in-season enhanced negative work-based training (ENT) vs weight training in the change of direction (COD), sprinting and jumping ability, muscle mass and strength in semi-professional soccer players. Forty male soccer players participated in the eight-week, 1 d/w intervention consisting of 48 squat repetitions for ENT using a flywheel device (inertia=0.11 kg·m^{-2}) or weight training (80%1 RM) as a control group (CON). Agility T-test, 20+20 m shuttle, 10 m and 30 m sprint, squat jump (SJ) and countermovement jump (CMJ), lean mass, quadriceps and hamstrings strength and the hamstrings-to-quadriceps ratio were measured. Time on agility T-test and 20+20 m shuttle decreased in ENT (effect-size =-1.44, 95% CI -2.24/-0.68 and -0.75, -1.09/-0.42 respectively) but not in CON (-0.33, -0.87/0.19 and -0.13, -0.58/0.32). SJ and CMJ height increased in both ENT (0.71, 0.45/0.97 and 0.65, 0.38/0.93) and CON (0.41, 0.23/0.60 and 0.36, 0.12/0.70). Overall, quadriceps and hamstrings strength increased in both ENT and CON (0.38/0.79), but the hamstrings-to-quadriceps ratio increased in ENT (0.31, 0.22/0.40) but not in CON (0.03, -0.18/0.24). Lean mass increased in both ENT (0.41, 0.26/0.57) and CON (0.29, 0.14/0.44). The repeated negative actions performed in ENT may have led to improvements in braking ability, a key point in COD performance. Semi-professional soccer players may benefit from in-season ENT to enhance COD and the negative-specific adaptations in muscle strength and hamstrings-to-quadriceps ratio.

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INTRODUCTION

A flywheel device allows the negative [1] phase accumulated by the inertia during the positive phase to be emphasized [2]. The possibility to enhance the strength exerted during the negative phase has led several authors to investigate its acute or long-term adaptations [3–9]. Additionally, it was recently concluded that training that used a flywheel device compared with traditional weight training may lead to equal [10] or superior [11] muscle strength and mass gains. This is based on the significant contribution of the negative phase in gaining muscle strength [12], irrespective of the exercise modality performed [13].

Enhanced negative work-based training (ENT) demands the athletes to repeatedly brake the body-mass inertia and subsequently accelerate it; thus it has been recently argued that ENT might mimic the change of direction (COD) demands [14], given the repeated brakes and accelerations occurring during CODs [15]. It was hypothesized that emphasizing the negative phase might result in favourable adaptations in COD ability [14]. However, few recent studies have confirmed this link [16–18], while no adaptation in COD was also reported [5]. Therefore, the authors of the aforementioned review [14] encouraged further studies on the possible ENT-induced adaptations in COD ability. In team sports and particularly in soccer, CODs affect the physiological demands, since a COD-based fatiguing test resulted in minor increases in heart rate, blood lactate concentration and perceived fatigue in COD-accustomed soccer players vs non-COD-accustomed fitness-matched athletes [19]. Additionally, the intermittent and unpredictable nature of soccer requires the players to perform explosive high-intensity activities, such as changing direction, sprinting and jumping [15]. Lower-limb muscle strength training has been included in the traditional weekly soccer routine to improve COD, sprinting and jumping ability [20–23]. However, less is known about the effectiveness of including ENT within the in-season weekly routine, given the lower players' sensitivity to the training-induced adaptations reported in season [21] than pre-season [24].

Squatting involves mostly lower-limb muscles, with a special emphasis on quadriceps and hamstrings. Interestingly, greater hamstrings vs quadriceps activation was observed during the negative vs positive squatting phase [25]. Consequently, the different negative-to-positive activation ratio in ENT vs traditional weight training could lead to specific adaptations in hamstrings and quadriceps strength, affecting the hamstrings-to-quadriceps ratio, used to monitor the hamstrings injury risk [26]. Therefore, the aims of the present study were to compare the in-season effects of ENT vs traditional weight training on: i) COD, sprinting and jumping ability; ii) quadriceps and hamstrings strength, hamstrings-to-quadriceps ratio and lower-limb muscle mass.

MATERIALS AND METHODS

Participants

Forty male soccer players (age: 23±4 years, body mass: 77±5 kg; height: 1.80±0.11 m) volunteered to participate. The participants joined two Italian fourth-division (Serie-D) soccer clubs, which competed in the Italian soccer championship. Within the season, their typical training volume consisted of four training sessions (about 2 hours per session) plus one match per week on Sunday, from September to May. The participants had soccer experience of at least five consecutive years in youth or semi-professional soccer teams. Lower-limb muscular or joint injuries in the previous 12 months, cardio-pulmonary diseases, smoking or the use of drugs were listed as exclusion criteria. The present investigation was approved by the local Ethical Committee and was in line with the Declaration of Helsinki (1975) concerning the ethical standards in studies involving human subjects. Finally, the participants were carefully informed about any possible risks due to the investigation's procedures and they signed a written informed consent form. They were also informed that they were free to withdraw from the study at any time.

Procedures

The present investigation was designed as a pre-post, parallel two-group randomized trial. The participants of the two soccer teams were randomly assigned to an ENT or traditional weight-training routine, used as a conventional training group (CON), i.e. the two teams had the same number of participants included in ENT or CON. The randomization followed two steps: 1) the players were randomized to two groups (1 and 2); 2) groups 1 and 2 were randomized as ENT or CON. Such a design was chosen to have an overall similar training routine in the two groups. No control group was used (i.e. players who did not perform any training), since it would have resulted in an unethical and impracticable approach [21], not suitable for the present in-season design. Thus, the players performed their weekly routine, including the dedicated strength session performed with either ENT or CON. To have a more ecological approach, the strength training session was placed in the middle of the week, according to the habitual coaches' scheduled routines. The weekly programme was planned with the clubs' staffs and is reported in Table 1.

TABLE 1. The in-season weekly programme for the semi-professional soccer players involved in the present study.

Day	Training Programme
Monday	Free
Tuesday	**Starters:** Warm-up, 15 min; Technical/tactical, 15 min; Low-/moderate-intensity aerobic training, 15 min; Strength training and injury prevention, 15 min. **Non-Starters:** Warm-up, 15 min; Technical/tactical, 15 min; Play, 30 min; High-intensity aerobic training, 20 min.
Wednesday	Strength training (ENT or CON) 20 min; Warm-up, 10 min; CODS and/or SSGs, 20 min; Technical/tactical, 25min; Play, 25 min.
Thursday	Warm-up, 15 min; Technical/tactical, 30 min; Play, 45 min.
Friday	Warm-up, 15 min; Speed training (long and short), 15 min Technical/tactical, 25 min; Play, 15 min.
Saturday	Free
Sunday	Match

ENT: enhanced-negative work-based training; CON: traditional weight training
CODs = Change of directions; SSGS = Small-sided games

The procedures lasted 10 weeks and were performed in season, from mid January to the end of March. The participants were instructed to avoid any further form of resistance workout for the entire duration of the investigation. In the first week, they were involved in three testing sessions. In the first session, they were familiarized with the squatting technique, isokinetic strength testing procedures, COD, sprinting and jumping ability testing procedures. During the second session, muscle architecture, lean mass (LM) and squat 1-RM were measured, and the participants were familiarized with the training protocols. During the third session, hamstrings and quadriceps isokinetic peak torque, COD, sprinting and jumping ability were measured. The intervention lasted eight weeks. Finally, the post-training testing measurements were conducted over two sessions. In the first one, LM, squat 1-RM and hamstrings and quadriceps isokinetic peak torque were measured. In the second session, COD, sprinting and jumping abilities were measured. Each assessment was performed by the same experienced operators, unaware of the participants' allocation, and interspersed by 30 min of passive recovery. COD, sprints and jumps were measured indoor, on a concrete surface.

Squat 1-RM

The 1-RM is a valid lower-limb strength measurement [27]. Back-squat 1-RM was measured using an Olympic bar (20 kg), following previous procedures [24]. After a standardized warm-up, consisting of 30 weight-free squats, the 1-RM attempts started from 80% of the body mass, given the non-specific strength-training experience of the participants. Thereafter, an additional 5% of the load was added until failure. Each set was separated by 3 min of passive recovery. The time under tension (2 s for the positive and negative phase, 1 s for the isometric phase) was standardized. The trial was valid once the participant lowered the thighs parallel to the ground. Strong standardized encouragements were provided to maximally perform each trial. Squat 1-RM / body mass was calculated and inserted into the data analysis.

Isokinetic measurements

An isokinetic dynamometer (Cybex Norm, Lumex, Ronkonkoma, USA) was used to measure quadriceps and hamstrings strength. The procedures followed previous protocols [28]. Briefly, the device was calibrated according to the manufacturer's procedures, and the centre of rotation was aligned with the tested knee [13]. The participants were seated on the dynamometer chair, with their trunk slightly reclined backwards and a hip angle of 85°. Two seatbelts secured the trunk and one strap secured the tested limb, while an additional lever secured the untested limb [29]. A standardized warm-up, consisting of three sets x 10 repetitions of weight-free squats, preceded the measures [24]. Quadriceps peak torque was measured in positive (60 $\text{deg}\cdot\text{s}^{-1}$) and negative (-60 $\text{deg}\cdot\text{s}^{-1}$) modality and hamstrings peak torque was measured in negative (-60 $\text{deg}\cdot\text{s}^{-1}$) modality, as previously assessed [24]. Each testing modality consisted of three maximal trials and was separated by 2 min of passive recovery. Strong standardized encouragements were provided to maximally perform each trial. The peak torque was then calculated and inserted into the data analysis. Finally, the negative-hamstrings to positive-quadriceps peak torque ratio (H_{ecc}:Q_{conc}) [26] was calculated. The dominant limb, defined as the preferred limb used to kick the ball, was tested [30]. *Excellent* test-retest reliability was found for all the isokinetic measurements (α = 0.900 - 0.944).

Lower-limb lean mass

Total body and regional composition were evaluated using DXA, a total-body scanner (QDR Explorer_W, Hologic, MA, USA; fan-bean technology, software for Windows XP version 12.6.1), according to the manufacturer's procedures. The DXA body composition approach assumes that the body consists of three components that are distinguishable by their X-ray attenuation properties: fat mass, LM and bone mineral [31]. The scanner was calibrated daily against the standard supplied by the manufacturer to avoid possible baseline drift. Data were analysed using standard body-region markers and the whole lower-limb LM amount was reported in the data analysis [24].

Squat jump and countermovement jump

The squat jump (SJ) and countermovement jump (CMJ) peak height was investigated using an infrared device (OptoJump, Microgate, Italy). In SJ, the participants were instructed to stand, flex the knees to approximately 90° and jump and to avoid any countermovement. In CMJ, they had to stand, reach a self-selected knee flexion and immediately jump. No knee flexion before the landing was allowed in both the SJ and CMJ, with arms on the hips. Three attempts were performed for each jump, and the peak height was inserted into the data analysis. Two minutes of passive rest separated each jump. *Excellent* reliability was found for the SJ (α = 0.938) and CMJ (α = 0.903).

Sprint and COD

The time trials of the agility T-test, 20+20 m shuttle and 10 m and 30 m sprint [15] were separately investigated using an infrared device (Polifemo, Microgate, Italy). The participants were placed 30 cm behind the starting line, with their preferred foot in a forward position and autonomously started each trial. *Excellent* reliability was found for the 10 m and 30 m sprint (α = 0.920 and α = 0.902, respectively).

The agility T-test was performed turning right or left first, and the sum of the two trials was inserted in the data analysis [24, 28]. A detailed description of the protocol was reported previously [24, 28]. The trials were not considered if participants failed to touch a designated cone or failed to face forward at all times. Only one timing gate placed on the start-finish line was used for timing the T-test. Each test was repeated three times, and the best performance was calculated and inserted into the data analysis. Two minutes of passive rest separated each trial. The agility T-test showed *good* reliability (α = 0.884).

The 20+20 m shuttle test was performed using two timing gates 20 m apart and a cone was placed 1 m beyond the second gate. The participants stood behind the first gate and had to sprint towards the second gate, touch the cone and sprint back to the first gate. The trial was not valid if participants failed to touch the cone. *Good* reliability (α = 0.867) was observed.

Intervention

The intervention was performed 1 d/w (Table 1). The ENT squat was performed using a flywheel ergometer (D11 full, Desmotec, Biella, Italy), while the CON squat was performed using an Olympic bar (Technogym, Cesena, Italy). Both ENT and CON sessions started with 20 weight-free squats. Then, ENT performed 10 submaximal flywheel squats and CON performed 10 squats with 50% 1-RM. The intervention consisted of four sets in the first week, five sets in the second week and six sets in the remaining weeks of eight repetitions for both ENT (inertia: 0.11 $kg \cdot m^{-2}$) and CON (80% 1-RM), interspersed by 3 min of passive recovery. The latter followed the specific seasonal strength protocol scheduled during the intervention period. The ENT inertial load was selected to have a similar muscle activity to result in a similar number of repetitions compared to CON [32]. ENT performed the positive phase as fast as possible and control the braking phase until the thighs were parallel to the ground. CON performed both the positive and the negative phase in approximately 2 s each, with a 1 s isometric stop when the thighs were parallel to the ground. A mirror was placed opposite to the participants to let them visually check their technique [7]. The participants received strong standardized encouragements to maximally perform each repetition.

Statistical analysis

Statistical analysis was performed using statistical software (SPSS 22, IBM, USA). The normality of the distribution was checked using the Shapiro–Wilk test. The test–retest reliability was measured using an intraclass correlation coefficient (ICC, Cronbach-α) and interpreted as follows: $\alpha \geq 0.9$ = *excellent*; $0.9 > \alpha \geq 0.8$ = *good*; $0.8 > \alpha \geq 0.7$ = *acceptable*; $0.7 > \alpha \geq 0.6$ = *questionable*; $0.6 > \alpha \geq 0.5$ = *poor* [33]. The variations in the dependent parameters were analysed by separate mixed-factors ANOVA (time × group) for repeated measurements. Post-hoc analysis using Bonferroni's correction was then performed to calculate the main effect for group (two levels: ENT and CON) and time (two levels: pre- and post-training). To detect the between-group differences in the training-induced percentage changes, the data were first log-transformed, and then an analysis of covariance (ANCOVA) was performed, assuming baseline values as covariates. Significance was set at $\alpha<0.05$. Descriptive statistics are reported as mean with standard deviation (SD). Changes are reported as %change with 95% confidence intervals (CI95%) and effect size (ES) with CI95%. ES was interpreted as follows [34]: 0.00–0.19: *trivial*; 0.20–0.59: *small*; 0.60–1.19: *moderate*; 1.20–1.99: *large*; ≥2.00: *very large*.

RESULTS

Time x group interactions were found for 20+20 m shuttle (F=5.568, p=0.028) and agility T-test (F=8.342, p=0.013), with *moderate* and *large* time decreases observed in ENT and non-significant *trivial* and *small* changes observed in CON, respectively (Table 2). No interaction was found for 10 m (F=3.122, p=0.168) or 30 m sprint

TABLE 2. Mean values (SD) of performances in COD, sprinting and jumping pre- and post-training are shown. Changes (%) and effect size are reported with confidence interval (CI95%).

	Pre: Mean (SD)	Post: Mean (SD)	Change (%) (CI95%)	Effect size (CI95%)
Shuttle 20+20 m (s)				
ENT	7.88(0.41)	7.52(0.32)	-4 (-6 to -2)*#	-0.75 (-1.09 to -0.42)
CON	7.91(0.45)	7.85(0.47)	-1 (-6 to 4)	-0.13 (-0.58 to 0.32)
Agility T-test (s)				
ENT	15.9(0.7)	14.8(0.8)	-7 (-12 to -2)*#	-1.44 (-2.24 to -0.68)
CON	15.8(0.8)	15.5(0.9)	-2 (-9 to 5)	-0.33 (-0.87 to 0.19)
10 m sprint (s)				
ENT	1.93(0.13)	1.90(0.08)	-2 (-5 to 2)	-0.23(-0.65 to 0.18)
CON	1.91(0.12)	1.89(0.12)	-1 (-4 to 3)	-0.12(-0.34 to 0.10)
30 m sprint (s)				
ENT	4.54(0.23)	4.47(0.20)	-2 (-3 to -0)	-0.32 (-0.60 to 0.04)
CON	4.58(0.25)	4.59(0.22)	-0 (-6 to 6)	-0.01 (-0.33 to 0.35)
SJ (cm)				
ENT	37.6(5.8)	41.8(5.9)	11 (6 to 16)*	0.71 (0.45 to 0.97)
CON	38.2(6.3)	40.8(6.7)	7 (4 to 10)*	0.41 (0.23 to 0.60)
CMJ (cm)				
ENT	39.5(7.1)	43.5(6.9)	10 (7 to 14)*	0.65 (0.38 to 0.93)
CON	39.9(7.4)	42.6(7.7)	7 (3 to 11)*	0.36 (0.12 to 0.70)

ENT: enhanced-negative work-based training; CON: traditional weight training.
SJ: Squat jump; CMJ: counter-movement jump.
* = $p < 0.05$ compared to pre; # = $p < 0.05$ compared to CON.

(F=2.941, p=0.201) and neither ENT nor CON experienced decreases in 10 m or 30 m time. (Table 2). Lastly, no time x group interaction was found for SJ (F=2.392, p=0.303) or CMJ (F=2.583, p=0.281). ENT and CON experienced *moderate* and *small* increases respectively in both SJ and CMJ peak height, with a between-group difference observed (Table 2).

Time x group interactions were found for quadriceps positive (F=5.021, p=0.042) and negative peak torque (F=5.439, p=0.031) and for H_{ecc}:Q_{conc} ratio (F=9.847, p=0.010). CON showed a *moderate* increase in quadriceps positive peak torque, greater than the *small* increase observed in ENT (+6%, CI95% 2/10) (Table 3). The *moderate* increase in quadriceps negative peak torque observed in ENT was greater than the *small* increase observed in CON (+7%, CI95% 3/11). ENT showed a *small* increase in H_{ecc}:Q_{conc} ratio. No group x time interaction occurred for squat 1-RM (F=3.233, p=0.218) or hamstrings negative peak torque (F=1.744, p=0.716). *Small* and *moderate* increases in squat 1-RM were found in ENT and CON respectively, while both ENT and CON had *small* increases in negative peak torque (Table 3). No time x group interaction was found for lower-limb LM (F=1.956, p=0.651). *Small* increases in lower-limb LM occurred in both ENT and CON (Table 3).

DISCUSSION

The current investigation highlighted that an in-season ENT vs CON intervention induced different adaptations in semi-professional soccer players. *Moderate*-to-*large* improvements in COD ability were observed only in ENT, with non-significant *trivial*-to-*small* changes in CON. No effect on sprinting ability was observed in ENT or CON. *Moderate* and *small* increases in SJ and CMJ peak height were observed in ENT and CON, with no between-group difference. Lastly, ENT showed *moderate* increases in quadriceps and hamstrings negative peak torque and a *small* rise in quadriceps positive peak torque and squat 1-RM. In contrast, CON showed *moderate* increases in squat 1-RM, quadriceps positive and hamstrings negative peak torque, accompanied by a *small* increase in quadriceps negative peak torque. This led to a *small* increase in H_{ecc}:Q_{conc} ratio observed only in ENT. Concurrently, *small* significant increases in lower-limb LM occurred in both ENT and CON.

When changing direction, strongly decelerating and accelerating immediately after is required. In line with the current outcomes, ENT improved COD in elite U18 soccer players [16]. This may depend on the decreased time spent to brake and increased braking impulse observed after ENT [18]. Consequently, the repetitive braking actions

TABLE 3. Mean values (SD) of quadriceps and hamstrings strength pre- and post-training are shown. Changes (%) and effect size are reported with confidence interval (CI95%).

	Pre: Mean (SD)	Post: Mean (SD)	Change (%) (CI95%)	Effect size (CI95%)
Squat 1-RM (Kg·BM^{-1})				
ENT	1.21(0.20)	1.30(0.22)	7 (2 to 12)*	0.40 (0.15 to 0.75)
CON	1.18(0.14)	1.33(0.21)	13 (6 to 20)*	0.73 (0.34 to 1.07)
Quadriceps PPT (N·m)				
ENT	226(39)	241(40)	7 (2 to 11)*#	0.39 (0.13 to 0.65)
CON	231(40)	264(41)	13 (5 to 21)*	0.80 (0.32 to 1.28)
Quadriceps NPT (N·m)				
ENT	281(62)	330(63)	17 (10 to 24)*#	0.79 (0.49 to 1.09)
CON	276(63)	301(64)	9 (2 to 16)*	0.39 (0.08 to 0.70)
Hamstrings NPT (N·m)				
ENT	195(46)	218(53)	12 (5 to 18)*	0.50 (0.27 to 0.73)
CON	191(46)	214(49)	12 (3 to 21)*	0.48 (0.14 to 0.82)
H_{ecc}:Q_{conc} (A.U.)				
ENT	0.88(0.22)	0.94(0.18)	7 (4 to 10)*#	0.31 (0.22 to 0.40)
CON	0.82(0.31)	0.81(0.29)	1 (-6 to 8)	0.03 (-0.18 to 0.24)
Lean mass (Kg)				
ENT	21.3(2.6)	22.4(2.8)	5 (3 to 7)*	0.41 (0.26 to 0.57)
CON	21.5(2.7)	22.3(2.7)	4 (2 to 6)*	0.29 (0.14 to 0.44)

ENT: enhanced-eccentric work-based training; CON: traditional weight training.
BM: body mass; PPT: positive peak-torque; EPT: negative peak-torque.
* = $p < 0.05$ compared to pre; # = $p < 0.05$ compared to CON

performed in the agility T-test vs the single turning action performed in the 20+20 m shuttle may have increased the extent of ENT-induced adaptations (*large vs moderate*, respectively) in ENT. Instead, the absence of enhanced negative actions in CON led to *trivial* changes in 20+20 m shuttle and non-significant *small* changes in agility T-test. No improvement in agility after strength training was also reported in elite soccer players [35]. In contrast, COD ability improved after long-term strength training added to the traditional weekly routine [36] or after an eight-week programme in junior soccer players [37]. However, the former involved the participants in a two-season training programme [36], while the latter involved young players who were likely unaccustomed and consequently more sensitive to strength training [37]. Thus, it seems that a traditional short-term strength-training programme does not appropriately stimulate the COD ability in accustomed soccer players. However, enhancing the negative phase may elicit the braking ability and transfer this to COD.

Non-significant *small* and *trivial* decreases in 10 m and 30 m sprint occurred in ENT and CON respectively. Traditional low-velocity resistance training was not effective in improving sprinting ability in physically active men [38]. In contrast, decreases in linear sprint time were reported in elite soccer players [20]. However, it should be acknowledged that the present procedures involved the participants in one single strength training session, in contrast with the two or more sessions in the previous study [20]. Additionally, this latter study used moderate intensity (40–60% 1-RM) that allowed very fast positive actions. Indeed, explosive training led to decreases in 10 m and 30 m sprint time [24, 38]. However, despite the explosive nature of the positive phase in ENT, the changes were not significant. Partially in line with the present outcomes, no change in 20 m sprint time occurred after specific resisted horizontal inertial flywheel training [5]. In contrast, two-to-three ENT sessions per week were reported to favourably affect the sprinting ability in handball players [11]. Therefore, it might be argued that one session per week might not be a sufficient stimulus to improve the linear sprinting ability when performed in season.

Moderate and *small* increases in SJ and CMJ peak height occurred in ENT and CON, respectively. Lower-limb muscle strength was reported to be correlated with jumping ability [39]. However, traditional weight training had a poor transfer to jumping ability, in favour of more explosive actions [23]. Indeed, training using loads that elicit maximum power was effective in increasing vertical jump height [24, 38] and the explosive nature of the positive phase in ENT was shown to increase muscle power [40], which turned into increases in SJ and CMJ height [6]. Notwithstanding, given the extent of the changes in sprinting and jumping ability in both groups, it should be remarked that the present investigation was conducted in season, i.e. a period in which the players are less sensitive to the training-induced improvements [21, 22].

Both ENT and CON increased hamstrings and quadriceps strength. However, this seemed to have followed specific training-testing adaptations; i.e. greater improvements occurred in the test that was similar to the training. Indeed, ENT quadriceps negative peak torque increased *moderately* compared to the *small* increases in quadriceps positive peak torque and squat 1-RM. Similarly, CON *moderately* increased quadriceps positive peak torque and squat 1-RM, while quadriceps negative peak torque increased by a *small* extent. The greater increases in quadriceps negative vs positive strength after negative-based training have already been reported [13, 41], as well as the greater increases in positive strength after positive-based training [42]. Interestingly, two different meta-analyses reported no difference [10] or greater strength increases [11] after ENT vs traditional weight training. Such discordance can be due to the studies' inclusion/exclusion criteria, as well as the several modalities used to assess muscle strength. Importantly, the strength training-testing specificity should be considered when measuring resistance training-induced adaptations [12]. The greater increases in quadriceps positive peak torque in ENT than CON might be related to the improvements in COD ability in ENT. Intriguingly, only ENT induced an increase in the H_{ecc}:Q_{conc} ratio, mainly due to the greater increases in quadriceps positive vs hamstrings negative peak torque in CON. This is associated with the greater hamstrings vs quadriceps activation recorded during the negative squat phase [25]. Although no previous study has directly investigated this, the current outcomes agree with the greater H_{ecc}:Q_{conc} ratio induced by greater negative inertia [24]. Hamstrings negative strength could help to monitor the strain injury risk, although this is a multifactorial phenomenon [43].

Small increases in lower-limb LM occurred in both ENT and CON. A minimum of 4-week strength training duration is needed to observe a hypertrophic response [44]. However, in an unaccustomed population, ENT caused an hypertrophic response in three weeks, even though the total number of sessions was similar to the present study [4]. Negative training is a powerful stimulus for increasing muscle size [12], even in trained populations [45]. Notwithstanding, ENT was not shown to be superior to traditional weight training [10]. Interestingly, one session/week effectively promotes muscle hypertrophy [44]. Particularly, the authors pointed out that higher frequency did not result in a greater muscle size increase when volume-equated. However, two further considerations need to be made. Firstly, the participants were involved in an in-season intervention, so less sensitive to the training-induced adaptations. Secondly, it cannot be excluded that a second session (thus increasing the volume) could have resulted in greater increases in LM. However, given the ecological procedures, this was not possible.

The present investigation has some limitations. Firstly, a methodological consideration needs to be acknowledged. Although the procedures were conducted to have similar between-group training volume, this might not have resulted in a perfectly equated amount of work. This occurs because, while traditional weight training volume could be calculated *a priori*, this is not possible using a flywheel device. However, the two loads used have a similar relative intensity [32]. Additionally, the whole weekly load could have been somewhat different between the two teams, although the authors together with the teams' staff carefully checked this. However, we are confident that the similar teams' level and in-season period might have resulted in a similar weekly load. Secondly, no control group was included. Although it could have reinforced the study design, it was not ethically acceptable to interrupt the in-season routine, and the clubs and the coaches would have refused their consent. Thirdly, power data were not collected. Although this could have reinforced the methodological procedures, such a technology is not often available among semi-professional teams. Lastly, given the specific routine used here, these data may only refer to semi-professional players. Further studies are needed to investigate the effects of ENT vs CON in different soccer populations.

CONCLUSIONS

The present outcomes suggest that a single weekly ENT session improved COD. In contrast, higher-frequency resistance training is needed to improve the sprinting ability in season [20]. In addition, the specific ENT-induced increases in H_{ecc}:Q_{conc} ratio leads to interesting injury prevention perspectives. Although specific exercises have been proposed to increase hamstrings strength (e.g. Nordic hamstrings), a non-specific ENT squat may be proposed for this aim. However, when a flywheel device is not available, a traditional squat should be coupled with hamstrings reinforcement.

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Conflict of interests

The authors declare no conflict of interests.

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