©Journal of Sports Science and Medicine (2020) **19**, 213-223
http://www.jssm.org

Research article

Isoinertial Eccentric-Overload Training in Young Soccer Players: Effects on Strength, Sprint, Change of Direction, Agility and Soccer Shooting Precision

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Abstract
The isoinertial training method owes its efficacy to an accommodated resistance and optimal individualized eccentric overload. The aim of this study was to assess the effects of a 6-week isoinertial eccentric-overload training program - using a flywheel inertial device during the execution of specific soccer exercises - on explosive and reactive strength, sprint ability, change of direction (COD) performance and soccer shooting precision. Thirty-four junior soccer players were randomly assigned to a plyometric training group (PT) (n = 16, aged 13.36 ± 0.80), which underwent a six-week traditional soccer training program, and a flywheel eccentric overload group (FEO) (n = 18, aged 13.21 ± 1.21), which received additional training consisting of two inertial eccentric-overload training sessions per week. Pre and post intervention tests were carried out to assess explosive and reactive strength, sprint ability, COD ability, agility using the Y-agility test (YT) and soccer shooting precision. The FEO showed significantly higher values than the PT in squat jump height (SJh) ($p = 0.01$), drop jump height (DJh) ($p = 0.003$), 7 repeated hop test heights ($p = 0.001$), the Illinois test (ILL) ($p = 0.001$), and the Loughborough Soccer Shooting Test (SHOT) ($p = 0.02$). Finally, the FEO showed significant between-group differences in DJh ($p = 0.007$), ILL ($p = 0.0002$), YT ($p = 0.002$), a linear sprint test (SPRINT) ($p = 0.001$), and SHOT ($p = 0.003$). These results confirmed the positive effect of isoinertial training. The use of an isoinertial device to overload multidirectional movements in specific sport conditions leads to greater performance improvements than conventional soccer training. The absence of knowledge of the eccentric overload applied by the isoinertial device, which is different in any exercise repetition, may stimulate the athlete's neural adaptations, improving their soccer skills and in particular their soccer shooting precision.

Key words: Gravity-independent flywheel device, multidirectional speed, unknown overload, eccentric strength training.

Introduction

The isoinertial training method, used to improve hypertrophy (Tesch et al., 2004; Norrbrand et al., 2008), neuromuscular functions (Norrbrand et al., 2010), power (Gual et al., 2016) and sprint time (Gonzalo-Skok et al., 2016) owes its efficacy to an accommodated resistance and optimal individualized eccentric overload (Tesch et al., 2017). The resistance intervention is based on the application of eccentric overloads generated by an isoinertial device, which uses the inertia of rotating flywheels during the athlete's movements. The flywheel technology, which simulates the mechanism of a toy yo-yo (Tesch et al., 2017), allows unlimited linear resistance loads during concentric and eccentric muscle actions, with the possibility of regulating the resistance overloads in each repetition. This device provides resistance force (in the eccentric phase) proportional to that generated by the athlete's concentric effort. The inertial force is generated by the rotating cone-shaped flywheel, which allows the athlete to move freely within the three spatial dimensions (Suarez-Arrones et al., 2018). The training load of this device can be regulated by increasing the speed of movement or by adding flywheel weights (Núñez et al., 2018). Due to the absence of frictional force, the energy of the concentric and eccentric phases is identical, allowing a great eccentric effort, with a very low metabolic cost (Caruso and Hernandez, 2002).

It is well known that the energy needed to perform eccentric actions is about one fifth of that required for concentric actions of the same cycle (Tesh et al, 2017). Several studies have pointed out that training protocols in which the eccentric phase of movement is overloaded, produce greater strength improvements than those in which the load is constant during both the concentric and eccentric phases (Doan et al., 2002). Prolonged eccentric exposure can enhance sport performance and prevent injuries (Martinez-Aranda and Fernadez-Gonzales, 2017). Cormie et al. (2010) reported that eccentric training improves concentric force and velocity, enhancing the storage and utilization of elastic energy. Several studies that have analyzed the effectiveness of the isoinertial method, have shown greater strength and power production, expressed in different joint angles (Dolezal et al., 2000). Eccentric strength is particularly needed in sports requiring Change of Direction (COD), where the athlete must decelerate and stabilize the body in the shortest possible time to then re-accelerate in a new direction (Chaabene et al., 2018). Since the phases of a soccer game require three-dimensional deceleration and acceleration actions with COD, (Fiorilli et al., 2017) the use of a cone-shaped device and transmission pulleys could provide additional benefit, allowing multidirectional movements in multiple planes (Chiu and Salem, 2006). Moreover, the accentuated eccentric phase enhances the neural adaptation that improves coordination and shooting precision (Norrbrand et al., 2010).

In recent decades a body of evidence has been developed that supports youth resistance training (di Cagno et al., 2013) as a fundamental means for physical development (Behm et al, 2008). Resistance training among youths

Received: 22 January 2019 / Accepted: 21 December 2019 / Published (online): 24 February 2020

is able to elicit improvements in overall motor performance and thus reduce the frequency of injuries (Zwolsky et al, 2017). Traditionally, plyometric training is used to overload the eccentric phase movement, allowing changes in the pattern of neural activation during the stretch-shortening cycle (SSC) and positively influencing the force and the start of the concentric phase (Chimera et al., 2004). Plyometric training is a safe and feasible method for physical conditioning in young athletes, improving neuromuscular function and soccer performance (Negra et al, 2017; Bedoya et al., 2015). Rubley et al. (2011) reported an improvement in kicking distance in prepubertal and pubertal soccer athletes after 10 weeks with twice-weekly sessions of plyometric training based on jumps, hops, skips, footwork and sprint drills. Nevertheless, plyometric training is based on the use of gravitational overloads, whereas inertial eccentric overload training provides a source of linear resistance from the spinning cone (Norrbrand et al., 2010). The eccentric overload provided by the isoinertial device may be applied directly to specific technical elements, such as COD and shooting movements, allowing the athlete to transfer the external variable overload effects to the real team sport performance. Moreover, isoinertial training provides unknown and unpredictable loads that stimulate different and continuous neuromuscular adaptations during each repetition (Van Hooren et al., 2017). A strong correlation has been found between isoinertial training and athletic performance with unknown loads (Hernández-Davó et al., 2017). This effect could lead to superior benefits than traditional plyometric training intervention.

Therefore, the aim of the present study was to assess the effects of flywheel inertial training on explosive and reactive strength, sprint ability, COD performance and soccer shooting precision, when compared to traditional plyometric training of the same duration and volume. To the best of our knowledge, no previous study has analyzed the effects of an inertial eccentric-overload training program on soccer shooting precision in young soccer players. It was hypothesized that athletes would benefit by adhering to a specific training program based on uncertain eccentric overloads used in similar conditions to those in which they compete, stimulating neuromuscular improvement and coordination.

Methods

Participants

Thirty-four junior male highly trained soccer players volunteered to participate in the present study and were randomly assigned to the FEO (n = 18, aged 13.21 ± 1.21, weight 51.25 ± 6.71 Kg, height 1.65 ± 0.10 m, BMI 19.16 ± 2.22 Kg/m^2) and the PT (n = 16, aged 13.36 ± 0.80, weight 52.10 ± 5.23 Kg, height 1.68 ± 0.07m, BMI 19.45 ±2.06 Kg/m^2). All players belonged to the same club and had at least 3 to 4 years of experience. Their regular exercise practice included 4 field-based training sessions lasting approximately 120 minutes and included warm-up, plyometric training, technical and tactical activities, small side games and one competitive match. All the players were new to structured eccentric overload training. To be eligible for the study, players were required to meet the following criteria: to be joint or bone injury free at the moment of recruitment and to not make use of drugs or other substances that could influence the correct execution of the tests proposed by this study. Information about the study purpose was given to all participants and their parents before obtaining their written consent. The study was designed and conducted in accordance with the Declaration of Helsinki and approved by the local bioethical committee.

Study design

The present study used a controlled randomized repeated-measure research design to assess the effects of six weeks of soccer training with the implementation of two inertial eccentric-overload training sessions per week, on young male soccer players. The effects on explosive and reactive strength, linear sprint, agility, and COD and shooting precision improvement were evaluated. The randomization in the FEO and the PT, was performed as follows: a progressive number was assigned to each of the 34 enrolled and eligible participants. Successively, a random number list (from 1 to 34 with no repeated numbers) was generated using online software (https://www.random.org/sequences/, Dublin, Ireland). The list of participants was rearranged according to the random number list; the participants were then allocated to the different groups in blocks of two participants per group following the order FEO and PT. Baseline homogeneity of the two groups was assessed after randomization (relative to all the primary and secondary outcomes).

The sample size (34 total participants) was calculated a priori with G*Power 3.1.9.4 (G*Power software, Dusseldorf, Germany). The computation of the total sample size was calculated using an a priori method in order to have an α error probability = 0.05 and a Power = 0.95 with Pillai' V = 0. Pre and post intervention, participants of both groups underwent a three -day testing session, to assess explosive and reactive strength, sprint ability, agility, COD ability, and soccer shooting precision (Figure 1).

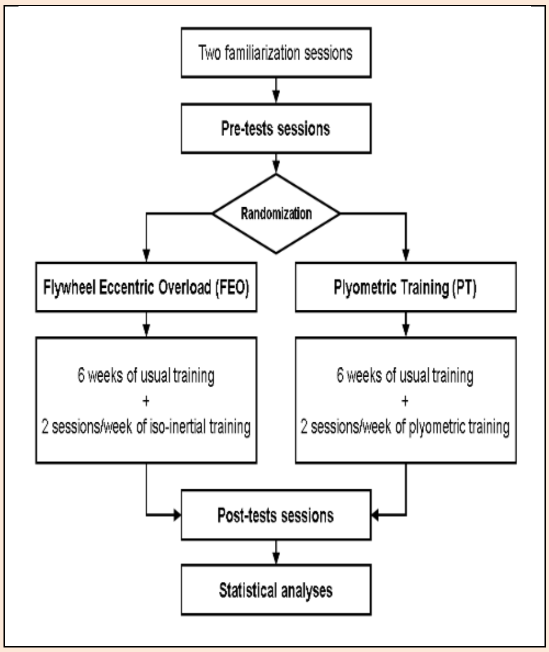

Figure 1. Study design.

Testing procedures

After the familiarization session, all participants took part in the testing session at the same time of the day in the same order: on the first day a lower-limb strength test was completed; on the second day there were COD, agility and sprint tests; and on the third day, the soccer shooting precision tests were performed. Participants were requested to avoid strenuous activities for at least 48 hours before each test.

The ground contact time and flight time of all jump tests were measured using Optojump (Microgate, Bolzano, Italy). This is an optical acquisition system, developed to measure flight time and ground contact time to a precision of 1ms. It has an excellent reliability, ranging from 0.982 to 0.989 (Glatthorn, 2011).

Squat Jump (SJ): In the squat jump test, participants were required to assume a static squat position with 90º knee flexion, and to perform a purely concentric action with the instruction to jump as high as possible (SJ_h). The knee angle was monitored with a Medigauge electronic digital goniometer and adjusted prior to each jump. The testers observed the subjects in order to identify any visual signs of countermovement. When countermovement was observed, the subjects were asked to repeat the attempt after 45 s of rest. Participants in the test were required to have their hands placed on their hips during the whole movement. Following three attempts interspersed by 45 s, the best performance was chosen for analysis.*Drop Jump (DJ:* In the DJ, the athletes stepped down from a measured drop height (0.3 m), landed on the ground and subsequently performed a maximal effort vertical jump measured in meters (DJh). Each participant was instructed to "jump as high as possible with the minimum ground contact time" (DJct). Subsequently, the reactive strength index of the jump was calculated by dividing jump height (m) by ground contact time (s) (DJRSI). Following three attempts interspersed by 45 s, the best performance was chosen for analysis.

7-Repeated Hop Test (7R-HOP): In the 7R-HOP Test, the athletes performed a series of seven continuous jumps with free arms, with a small amplitude counter movement and a short ground contact time. 7R-HOP_h represented the average height and 7R-HOP_tc the average contact time of the 7 jumps. The 7R-HOP Test was used to assess the stiffness and the reactive strength index of the seven jumps, calculated as [Average Jump Height (m) / Average Ground Contact Time (s) (7R-HOP_RSI)] (Healy et al, 2016). The test reliability between and within sessions is 0.40-0.90 and 0.87-0.98, respectively (Mok, 2016).

Y-agility Test (YT): The YT is used to evaluate agility. This test was carried out in reactive mode. Each participant was asked to sprint as fast as possible for 5 m through a trigger timing gate (start gate), followed by a 45° cut and 5 m sprint to the left or right through a target gate (Munro,2011). The participants did not know the cut direction, having to run towards the gate that illuminated. The illumination of the target gate was activated by photocells positioned 2.5 m from the start gate. The time to complete the 10m of the test was recorded by software and photocells (Microgate, Bolzano, Italy), and the best time of eight attempts was considered for the analysis (Figure 2A).

Illinois Change of Direction Test (ILL): The ILL is set up with four markers forming a rectangular area of 9.3 × 7.2 m (ICC 0.8 - 0.9; Hachana, 2014). The start and the finish gates were positioned at two consecutive angles of the rectangular area, and two markers were positioned on the opposite side to indicate the two turning points. A further four markers were placed in the center at an equal distance apart (3.1 m). From the start gate, the participant had to run as quickly as possible following a planned direction, performing a slalom through the markers, without knocking or cutting across them. Therefore, on command, from a standing position, each athlete sprinted 9.3 m and then returned to the starting line; they then had to swerve in and out of the markers; they then completed another sprint of 9.3 m; and finally, they completed the test by passing through the finish gate. When each participant went through the finish gate, the time was recorded by software, which measured the time spent between the start gate and finish gate photocell detections (Microgate, Bolzano,

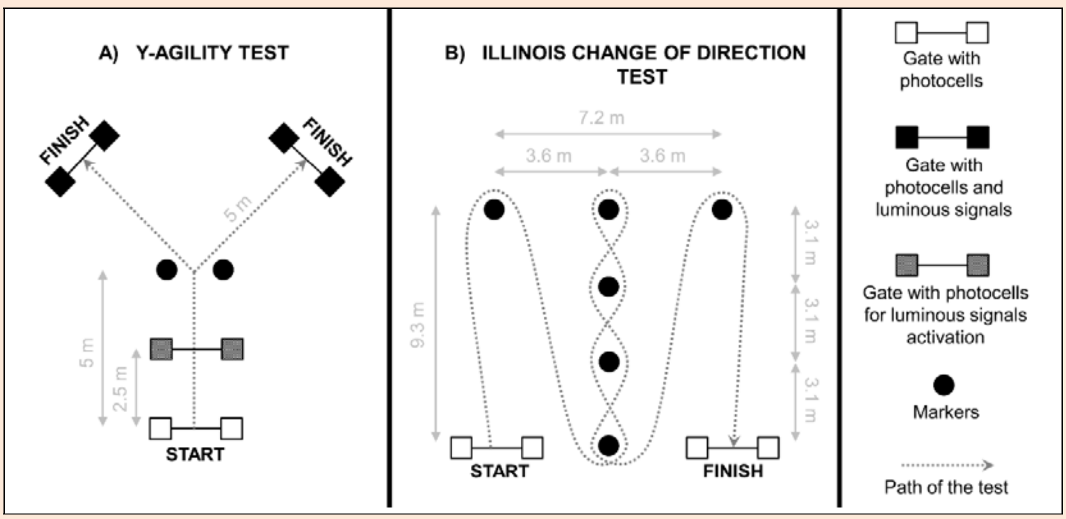

Figure 2. Graphic illustration of the Y-agility test and Illinois Change of Direction tests.

Italy), and thus the test was complete (Figure 2B). If a subject failed to complete the test, the trial was stopped and re-attempted after the required recovery period. The best time of three attempts was recorded as the ILL score. ILL therefore represented the time used to complete the Illinois test.

Linear Sprint Test (SPRINT): Participants were assessed over a 60 m linear sprint test; this was conducted outdoors with suitable weather conditions on an artificial turf field. Sprint time was recorded with photoelectric cells (Racetime2, Microgate, Bolzano, Italy). The front foot was placed 0.5 m before the first timing gate, and players started when ready, eliminating reaction time. Two trials were completed, and the best performance trial was used (SPRINT). Three minutes of passive rest were permitted between 60 m trials. (ICC 0.79-0.94; Hachana, 2014).

Loughborough Soccer Shooting Test (SHOT): Soccer shooting precision was assessed using the Loughborough Soccer Shooting Test (ICC 0.64-0.75; Ali et al., 2007). All boundary lines of the test were marked on the floor using 5-cm grey tape. The 'shooting zone' was a square (8.56 × 8.5 m), with the nearest line 16.5 m from the goal line. Four tall traffic cones were placed on each corner of the shooting zone (Figure 3). A standard gymnasium bench was placed in the middle of the far side of the zone to act as a rebound board. A full-size soccer goal measuring 2.44 × 7.32 m was split into scoring zones. SHOT represented the best score obtained on three attempts at the goal-zone. As in a previous study (Stone and Oliver, 2009), a life-size goalkeeper and a radar to measure shot speed were not used in the present investigation.

Experimental setup

Applying the concept of the yo-yo system to the sporting context, isoinertial training uses this principle for the kinetic energy accumulation in a flywheel. During the athlete's concentric phase of movement, a rope linked to the flywheel is fully wound, off storing energy in the system. In the eccentric phase, by pulling the strap back onto the shaft, the system produces a resistance due to the traction rope tension in response to the power expressed, until the flywheel is brought to a stop. The eccentric action absorbs the energy stored in the flywheel. The Flyconpower conical machine (Cuneo; Italy), used in this study offers versatility to replicate training movements. It can recreate a real and functional stimulus due to a variable speed, intensity, acceleration and deceleration. Specific multi-plane, multi-joint movements can be performed at their maximum power output, thanks to the conic form of the flywheel. The resistance is proportional to the athlete's effort developed in each repetition and the eccentric overload is adjusted to a possible decrease in strength due to fatigue.

Experimental intervention

In addition to their usual training, the participants of the FEO, during the 6 weeks of the study intervention, took part in 2 sessions per week of isoinertial training. Each session consisted of 4 sets of 7 repetitions for each exercise with 120-180 s of rest between sets, and with at least 48 hours of recovery between sessions. For the FEO, the isoinertial training represented ~18% of the total soccer training time, and replaced the plyometric training performed by the PT. The PT, during the 6 weeks of experimental

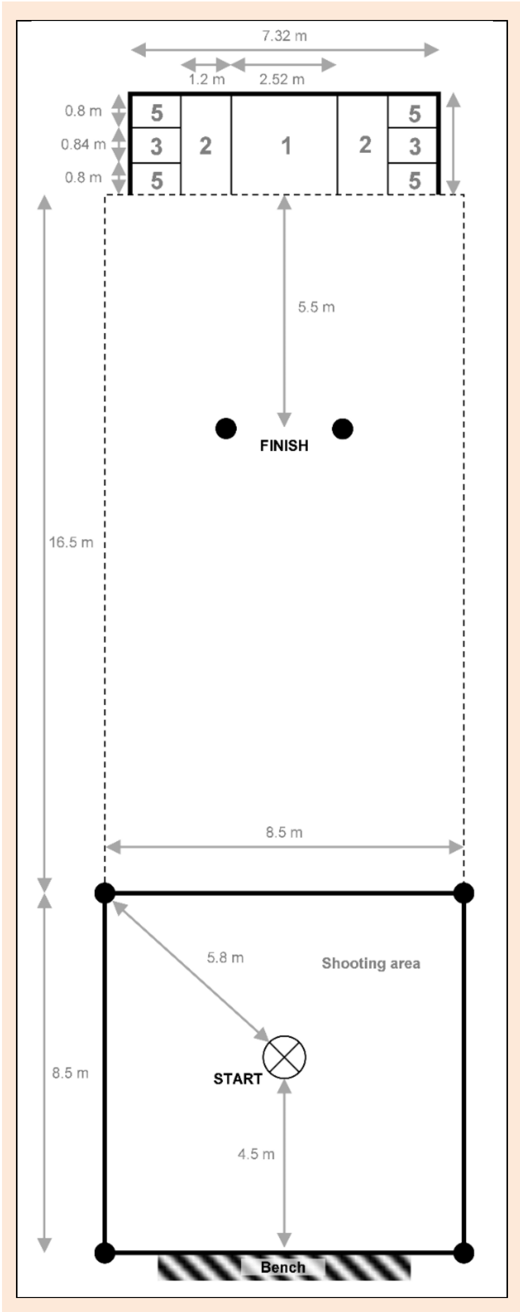

Figure 3. Graphic illustration of the Loughborough Soccer Shooting Test.

performed by the PT. The PT, during the 6 weeks of experimental intervention, performed their usual weekly training, which included a plyometric protocol, carried out at the same time and in place of the FEO isoinertial protocol. The plyometric protocol consisted of 4 exercises (3/4 sets x 7/10 reps for each one), twice a week, with a 72-hour rest period between plyometric training days. After 8-12 min of low intensity warm-up in the first weekly session, training was based on exercises oriented towards improving vertical components of strength, such as drop jumps; in the second week, exercises to improve horizontal jumping ability were chosen. During the 6 weeks, the training volume was progressively increased.

The plyometric protocol was based on previously published recommendations for training intensity and volume by Bedoya et al. (2015). Participants completed two familiarization sessions to ensure appropriate technique for each isoinertial exercise. This low-load/high-speed protocol aimed to stimulate power gains in young athletes. The isoinertial eccentric overload program consisted of two typologies of exercise. The first one was defined by two multidirectional-unilateral exercise typologies simulating COD performance. The exercise sequence was carried out performing a 4 m- sprint in a diagonal direction with an isoinertial device fixed on the waist. Each participant was asked to sprint as fast as possible to the left or to the right towards a target gate, which was randomly indicated by the coach. Participants were encouraged to apply the maximum effort during the concentric phase of sprinting forward and then asked to resist the eccentric phase of movement by back-pedaling (Figure 4). The second exercise typology consisted in a shot movement, which simulated soccer shooting, with the device fixed to the athlete's ankle. The player performed the knee extension movement with both legs, first keeping their backs to the device, and subsequently with the device in front. The hip angle was about 45/50°, which took into consideration the participants' age and replicated the soccer specific action of kicking and shooting.

During the training with the flywheel device, athletes were encouraged to perform the concentric phase as fast as possible, delaying the braking action until the end of the eccentric phase. The experimental protocol is shown in Table 1.

Statistical analysis

Multivariate analysis of variance for repeated measures (RM-MANOVA), was used to evaluate significant differences between the two groups (FEO vs. PT- the between factor of the analysis, named Group), between the pre-test and post-test scores (PRE vs. POST the within factor of the analysis, named Time), and in the interaction, Group×Time. The following 11 dependent variables were considered for the analysis: SJh, DJh, DJct, DJRSI, 7R-HOPh, 7R-HOPtc, 7R-HOPRSI, ILL, YT, SPRINT, and SHOT. After the multivariate analysis, univariate analysis was performed for each variable in order to evaluate the significant modification of each score. Univariate analysis was performed using the groups (FEO vs. PT) as the between factor of the analysis and using the pre-tests and post-test scores (PRE vs. POST) as the within factor of the analysis. The interaction Group×Time, was also considered.

The analysis was performed using SPSS (v.25, IBM). The level for significance was set at 0.05. For a better interpretation of the results, partial eta squared (η_p^2) was calculated as an indicator of effect size: η_p^2 below 0.01, 0.06, and 0.14 were considered as small, medium, and large effect sizes, respectively.

Figure 4. Example of an isoinertial exercise.

Results

Data are presented as means ± standard deviation (SD). There were no differences in any variables considered at pre-intervention tests. The RM-MANOVA showed significant differences between the 2 groups ($F_{11,30}$ = 3.793; p = 0.002; η_p^2 = 0.582), between the PRE vs. POST assessments ($F_{11,30}$ = 14.030; p <0.0001; η_p^2 = 0.837), and in the interaction Group×Time ($F_{11,30}$ = 3.874; p = 0.002; η_p^2 = 0.587).

The univariate analysis showed significant differences over time in DJh ($F_{1,40}$ = 10.355; p = 0.003; η_p^2 = 0.206), in DJct ($F_{1,40}$ = 10.149; p = 0.003; η_p^2 = 0.202), in 7R-HOPh ($F_{1,40}$ = 8.528; p = 0.006; η_p^2 = 0.176), in SJh ($F_{1,40}$ = 22.840; p < 0.0001; η_p^2 = 0.363), in the ILL ($F_{1,40}$ = 55.780; p < 0.0001; η_p^2 = 0.582), in YT ($F_{1,40}$ = 42.888; p <0.0001; η_p^2 = 0.517), in SPRINT ($F_{1,40}$ = 38.751; p <0.0001; η_p^2 = 0.492), and in SHOT ($F_{1,40}$ = 49.783; p <0.0001; η_p^2 = 0.554). No differences over time were instead observed in DJRSI, 7R-HOPtc, and 7R-HOPRSI.

Differences between groups were found in DJh ($F_{1,40}$ = 9.637; p = 0.003; η_p^2 = 0.194), in 7R-HOPh ($F_{1,40}$ = 13.712; p = 0.001; η_p^2 = 0.255), SJh ($F_{1,40}$ = 7.105; p = 0.01; η_p^2 = 0.151), in ILL ($F_{1,40}$ = 11.813; p = 0.001; η_p^2 = 0.228), and in SHOT ($F_{1,40}$ = 6.027; p = 0.02; η_p^2 = 0.131). Conversely, no differences between groups were observed in the other variables.

Table 1. Load progression across the 6-week training period.

	Flywheel Eccentric Overload group (FEO)	Plyometric Training group (PT)
Week 1	2 sessions; 2 exercises for each session; (4 sets x 7 reps)	2 sessions; 2 exercises for each session; (3 sets x 7 reps)
Week 2	2 sessions; 2 exercises for each session; (4 sets x 7 reps)	2 sessions; 2 exercises for each session; (3 sets x 8 reps)
Week 3	2 sessions; 2 exercises for each session; (4 sets x 7 reps)	2 sessions; 2 exercises for each session; (3 sets x 9 reps)
Week 4	2 sessions; 2 exercises for each session; (4 sets x 7 reps)	2 sessions; 2 exercises for each session; (4 sets x 8 reps)
Week 5	2 sessions; 2 exercises for each session; (4 sets x 7 reps)	2 sessions; 2 exercises for each session; (4 sets x 9 reps)
Week 6	2 sessions; 2 exercises for each session; (4 sets x 7 reps)	2 sessions; 2 exercises for each session; (4 sets x 10 reps)
Load increase	Increasing the weight of the flywheel, in order to obtain a Rate of Perceived Exertion = 17 based on Borg's Scale.	Increasing the number of sets and reps, in order to obtain a Rate of Perceived Exertion = 17 based on Borg's Scale.
Exercises description	4 meters sprint in diagonal direction; Soccer shooting simulation	Drop jump height 20 cm; Box jumps height 20cm; Speed ladders

Table 2. Scores obtained in the different tests with pairwise analyses results.

		Pre	Post	Δ (Post-Pre)	*Sign.*[a]	Effect size (η_p^2)[c]
		Mean ± SD	Mean ± SD			
DJh (cm)	FEO	26.99 ± 3.23	30.33 ± 4.29	3.34	$p = 0.001$	*Time:* 0.206 *Group:* 0.194
	PT	25.25 ± 3.83	25.47 ± 3.91	0.22	*NS*	
	Sign.[b]	*NS*	$p = 0.004$			
DJct (s)	FEO	0.48 ± 0.12	0.58 ± 0.08	0.10	$p = 0.03$	*Time:* 0.202
	PT	0.54 ± 0.11	0.60 ± 0.16	0.06	*NS*	
	Sign.[b]	*NS*	*NS*			
DJRSI (m/s)	FEO	0.57 ± 0.10	0.54 ± 0.16	-0.03	*NS*	
	PT	0.50 ± 0.13	0.46 ± 0.14	-0.05	*NS*	
	Sign.[b]	*NS*	*NS*			
7-RHOPh (cm)	FEO	20.78 ± 5.25	24.64 ± 3.40	3.86	$p = 0.003$	*Time:* 0.176 *Group:* 0.255
	PT	17.36 ± 6.56	18.92 ± 3.66	1.56	*NS*	
	Sign.[b]	*NS*	$p < 0.001$			
7-RHOPct (s)	FEO	0.25 ± 0.10	0.31 ± 0.09	0.06	*NS*	
	PT	0.27 ± 0.08	0.26 ± 0.08	-0.01	*NS*	
	Sign.[b]	*NS*	*NS*			
7-RHOPRSI (m/s)	FEO	0.84 ± 0.18	0.83 ± 0.18	-0.01	*NS*	
	PT	0.70 ± 0.30	0.76 ± 0.19	0.05	*NS*	
	Sign.[b]	*NS*	*NS*			
SJh (cm)	FEO	23.89 ± 6.60	28.02 ± 2.60	4.13	$p = 0.006$	*Time:* 0.363 *Group:* 0.151
	PT	20.72 ± 6.64	23.76 ± 2.90	3.04	$p = 0.008$	
	Sign.[b]	*NS*	$p < 0.001$			
ILL (s)	FEO	22.08 ± 1.74	18.85 ± 0.62	-3.23	$p < 0.001$	*Time:* 0.582 *Group:* 0.228
	PT	23.07 ± 2.45	22.12 ± 2.82	-0.94	$p = 0.03$	
	Sign.[b]	*NS*	$p < 0.001$			
YT (s)	FEO	2.87 ± 0.14	2.61 ± 0.15	-0.26	$p < 0.001$	*Time:* 0.517
	PT	2.80 ± 0.15	2.72 ± 0.13	-0.08	*NS*	
	Sign.[b]	*NS*	*NS*			
SPRINT (s)	FEO	10.40 ± 0.50	10.16 ± 0.56	-0.24	$p < 0.001$	*Time:* 0.492
	PT	10.49 ± 0.45	10.42 ± 0.49	-0.07	*NS*	
	Sign.[b]	*NS*	*NS*			
SHOT (score)	FEO	1.89 ± 0.58	2.89 ± 0.90	1.00	$p < 0.0001$	*Time:* 0.554 *Group:* 0.131
	PT	1.68 ± 0.61	2.06 ± 0.85	0.38	$p = 0.008$	
	Sign.[b]	*NS*	$p = 0.04$			

[a]: significance pre *vs.* post (with correction for multiple comparisons); [b]: significance FEO *vs.* PT (with correction for multiple comparisons) effect size was reported for significant results as Partial eta squared (η_p^2); [c]: $\eta p2$ below 0.01, 0.06, and 0.14 describe small, medium, and large effect sizes, respectively. *NS*: not significant

Finally, significant interactions were found in DJh ($F_{1,40} = 8.000$; $p = 0.007$; $\eta_p^2 = 0.167$), in ILL ($F_{1,40} = 16.746$; $p = 0.0002$; $\eta_p^2 = 0.295$), in YT ($F_{1,40} = 10.994$; $p = 0.002$; $\eta_p^2 = 0.216$), in SPRINT ($F_{1,40} = 11.862$; $p = 0.001$; $\eta_p^2 = 0.229$), and in SHOT ($F_{1,40} = 10.286$; $p = 0.003$; $\eta_p^2 = 0.205$). In contrast, no differences were found in DJct, DJRSI, 7R-HOPh, 7R-HOPtc, 7R-HOPRSI, and SJh.

The results are reported in Table 2 as means and standard deviation. In Figure 5, the 5 parameters with significant Group×Time interactions only were reported, for an easier interpretation of the results.

Discussion

There are several important findings in this study. Both the FEO and PT groups, significantly improved jump height after 6 weeks of training. Conversely, the FEO showed bet ter results in ILL and SHOT tests than the PT. These responses were mode-specific. Therefore, on the one hand plyometric training can be beneficial for facilitating enhancements in DJ_h, 7-RHOP h and SJ_h, in particular. On the other hand, when applied to specific soccer movements such as COD and SHOT, an isoinertial eccentric overload device, can significantly improve performance, more so than plyometric training. The possibility of using an isoinertial device to overload multidirectional movements (forward, backward and lateral), in different joint angles, and in specific sport conditions, has led to better adaptations and performance improvements than those seen in conventional training. Previous studies have applied flywheel eccentric overload in the training of youth soccer players, showing significant improvements in body composition and both concentric and eccentric strength (Suarrez-Arrones et al., 2019; Nunez et al., 2019).

The main finding and the novelty of the study is that soccer shooting precision significantly improves after isoinertial training as demonstrated by the significant differences between the FEO and the PT in the Loughborough Soccer Shooting Test, post-test. We hypothesized that this result was due to the absence of knowledge of the eccentric overload applied by the isoinertial machine, which stimulates different and constant adaptations of the athlete's neuromuscular system and coordination in any exercise repetition (Hernández-Davó et al., 2017). It has been demonstrated that athletic performance improves after training intervention with unknown loads (Sabido et al., 2016). Since soccer is a sport in which the uncertainty both of the loads and the work environment characterizes performance, athletes could benefit by adhering to an isoinertial training program, which applies similar stressors and environments

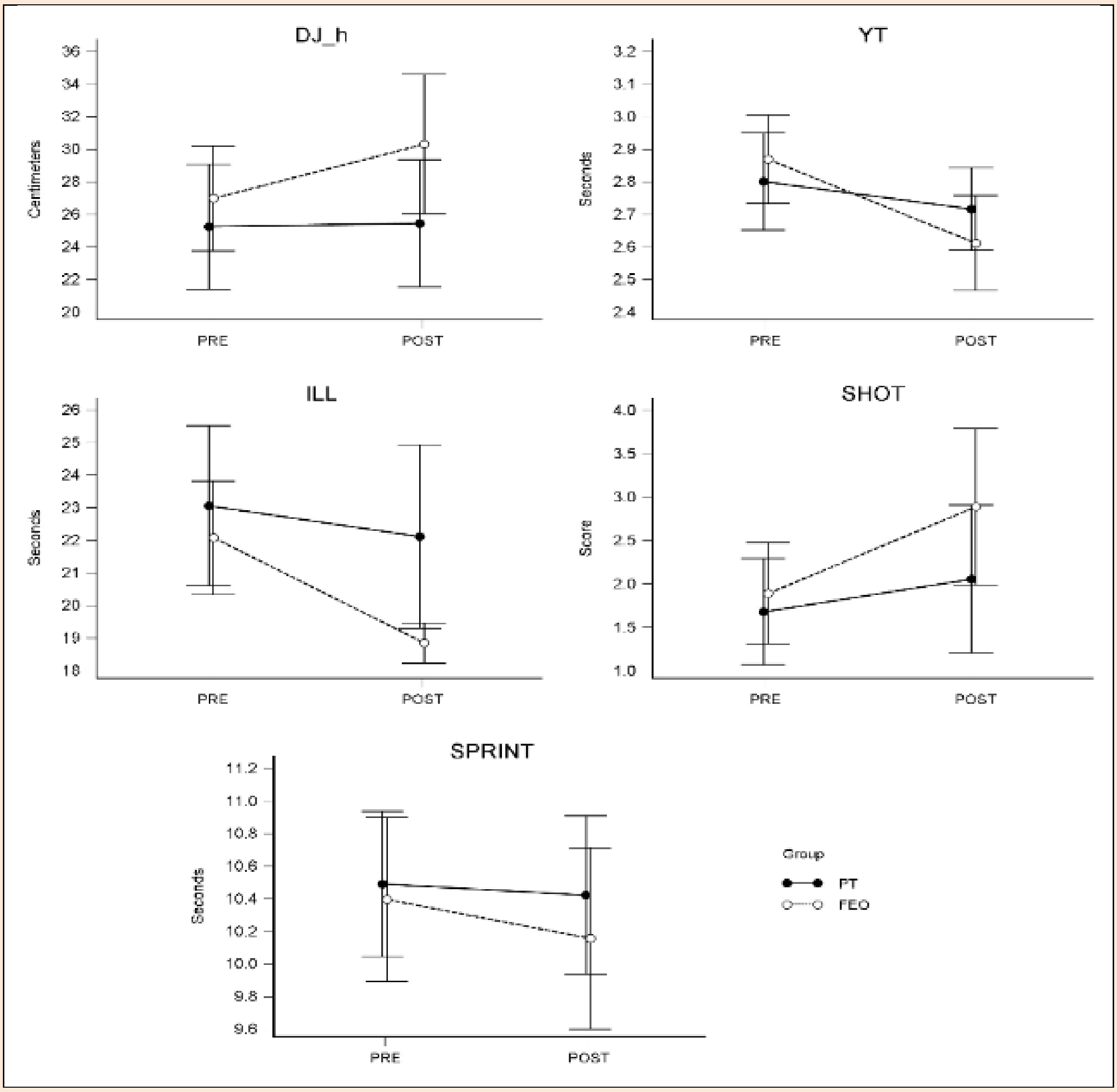

Figure 5. Results in the 5 variables with significant interactions Time*Groups.

(Leventer et al., 2015). Another mechanism that explains the improvement in movement may be the muscle activation due to the involvement of both central voluntary activation of motor programs and the increase of reflex-mediated muscle activation after isoinertial training as shown by Shapiro et al. (2002; 2004). As Martinez-Aranda and Fernandez-Gonzalo (2017) have highlighted, the better adaptations induced by isoinertial training are explained by the powerful stretch reflex produced in the eccentric-concentric transition, during flywheel resistance training. It has been hypothesized that the withholding of the variable load information in each isoinertial training repetition is associated with an increased pre-activation of the muscles involved. This is a response to a potential over-estimation of the load (Commissaris and Toussaint, 1997), which causes greater eccentric phase adaptations.

Isoinertial training improves eccentric velocity and eccentric kinetic energy on performance (Gonzalo-Skok et al., 2016; Núñez et al., 2018). It appears that prolonged eccentric exposure and brief episodes of very high activity in the SSC improves eccentric action, such as that in DJ, the SSC and the first phase of COD. Interestingly, it also improves the successive concentric phase of strength, such as that assessed in SJ, in the second phase of COD and in sprinting, more so than in training with traditional resistance exercise protocols (Spiteri et al., 2014; Mellos et al., 2014). The influence of eccentric phase performance on the concentric phase depends on different mechanisms (Cormie et al., 2010). A faster stretching phase leads to an increase of storage and release of energy available at the end of the eccentric phase, allowing an improvement of kinetic energy seen in movement velocity (Hernández-Davó et al., 2017). During COD an athlete needs eccentric force to rapidly decelerate and concentric strength to accelerate in a new direction (Ben Abdelkrim et al., 2010). Moreover, shooting ability benefits from both concentric and eccentric strength improvement (Ali, 2011). These significant strength improvements may be explained by the results of

Seynnes et al. (2007), who showed a significant increase in muscle fascicle length and pennation angle after 12-15 days of isoinertial training. These architectural changes may have increased force producing capacity. Moreover, it has been demonstrated that eccentric strength stimulates the addition of sarcomeres in series, which increases the muscle fascicle length (Franchi et al., 2014). Since the effects of isoinertial training are based on prolonged eccentric exposure, improvements in DJ and the 7-RHOP test were to be expected. In terms of performance, greater tendon stiffness plays a critical role in rapidly transmitting strength from the muscles to the skeletal system (Mersmann et al., 2016). Stiffness allows a greater speed recoil of the muscle-tendon units, positively influencing the transition (eccentric-concentric) point of the SSC exercises and increasing stretch reflex activity (Horita et al., 2003). A better muscle-tendon stiffness and reactive strength was obtained by the FEO as demonstrated by the significant amelioration in 7-RHOP_h and DJ_h values. However, in the DJ_ct, the time significantly increased in the FEO but not in the PT. The results did not demonstrate better 7-RHOP_ct and RSI. It is our opinion that this difference can be explained by the adoption by the FEO of a different jump strategy after the isoinertial training, consisting in a longer time of application of strength in the take-off phase, which allowed a higher flight time, which consequently improved the height of the jumps.

Significant differences between groups in almost all the tests evaluated were found. The experimental program aimed to improve power during the critical transition from eccentric to concentric action both in a stretch-shortening single-plane movement (jumping ability) and, as has been previously underlined, as a way to improve the ability to express power during multidirectional tasks, such as COD. Conventional training programs that include gravity-dependent weight exercises, performed in a vertical direction, such as Olympic style lifts and plyometric squats have failed to induce COD performance improvements (Brughelli et al., 2008). The isoinertial tasks proposed in the flywheel eccentric overload protocol were organized to simulate the complex movement patterns typical of COD and shooting performance, while the athlete simultaneously experienced eccentric overloads. The results of previous studies have revealed better physiological responses and greater stimuli offered by isoinertial training when compared to traditional weight training (Tesch et al., 2017, Bourgeois et al., 2017). In particular, a previous study found an improvement in professional footballers in vertical power and horizontal speed (de Hoyo et al. 2015). In addition, Tous-Fajardo et al. (2016) showed an enhancement of COD ability and COD speed following conventional soccer training, due to the possibility of maneuvering the eccentric overload in multiple planes, and of using the inertia of rotating flywheels throughout the entire range of any concentric action (Tesch et al., 2004). Moreover, electromyography activity during isoinertial eccentric overload training greater than that recorded during all-out exercise using traditional weights was observed by Onambélé (2008) and Norrbrand (2010). Similar adaptations are due to marked neural adaptations (Seynnes et al., 2007). Bourgeois (2017) and Tous-Fajardo (2016) also found isoinertial training benefits for COD tasks in young soccer players, in accordance with the present study. No significant differences between the FEO and the PT in linear-sprint performance were observed. It is noteworthy that the two protocols used in this study showed comparable improvements. This result is supported by previous studies (Tous-Fajardo et al., 2016; Buchheit et al., 2010).

The improvement in shooting precision may be due to both a greater improvement in proprioception, following isoinertial training than in weight lifting, as was reported in a previous study (Hedayatpour and Falla, 2015; di Cagno et al., 2014), and to a kind of post activation potentiation (also named PAP) which enhances the successive neuro-motor performance (Cuenca-Fernández et al., 2015). This post activation potentiation effect is more evident after the FEO method than in traditional resistance training.

Finally, the significant interactions between groups, in DJ_h, YT, ILL, SPRINT and SHOT precision seem to confirm the positive effect of isoinertial training. Indeed, as shown in Figure 4, the FEO tends to have greater improvements in these tests, compared with the PT. The findings of our study should be viewed in the context of the following limitations: The amount of eccentric overload was not adjusted on an individual player basis; the decision was made to focus on young soccer players, which limits the possibility of generalizing the results to adult players with a higher level of expertise. Electromyography was not used to obtain information about muscle neural activation during the experimental training and the reliability of the test protocols used were not evaluated, which leads to uncertainty over the actual magnitudes of change reported in this study.

Conclusion

Findings from the present study revealed that isoinertial eccentric overload training led to greater improvements in almost all the variables studied compared with traditional soccer training. Eccentric velocity and eccentric kinetic energy have high positive effects on rapid force production in soccer performance. The possibility of an isoinertial device being used to overload multidirectional movements (forward, backward and lateral), in different joint angles, and in specific sport conditions, leads to better adaptations and performance improvements than conventional soccer training. The coordinative tasks required in the different phases of the isoinertial training, which stimulated shoot precision in a different way to plyometric training make this kind of training particularly useful for youth soccer players. Therefore, especially in young athletes, there is a need to introduce different and more-challenging training methods (Fiorilli et al., 2017) that can stimulate eccentric kinetic energy gains and enhance complex skill efficiency in real game situations.

Acknowledgements
The experiments comply with the current Italian laws. The study was carried out with no external financial support. No conflicts of interest are declared for any of the authors.

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Key points

- The iso-inertial eccentric training evoked greater improvements than traditional soccer training.
- The soccer shooting precision, significantly improved after iso-inertial training.
- The iso-inertial device allows to overload multidirectional movements in specific soccer conditions.

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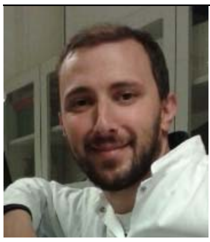

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