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Research article

Effects of Accentuated Eccentric Training vs Plyometric Training on Performance of Young Elite Fencers

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Abstract
The aim of the study was to evaluate the effects of 6-weeks accentuated eccentric training, using a rotary inertial device, on range of motion, assessed with Inter Malleolar Distance test, anthropometry, lower limb explosive and reactive strength, assessed with Squat Jump, Countermovement Jump and 7-Repeated Hop tests, in young elite fencers. Moreover, the effects on hamstring eccentric strength and two technical fencing movements, lunge and advance-advance lunge, were evaluated with motion analysis. The second aim was to evaluate the duration of the accentuated eccentric training residual effects, 6 weeks after the end of the training. Fifty-four male fencers were randomly assigned either to the Inertial Group (IG; n = 26; aged 17.3 ± 1.9 years) such as experimental group, or to the Plyometric Group (PG; n = 28; aged 17.6 ± 2.7 years) such as control group. IG carried out four exercises using the rotary inertial device attached to their waist by a rope. PG carried out several plyometric exercises at the same time in which the IG performed the accentuated eccentric training. MANOVA showed significant improvements in the vertical jumps height post training, with no differences between IG and PG. Significant improvements for technical movements, lunge distance ($p = 0.006$) and advance-advance lunge distance ($p = 0.00005$), were found within-group and between-groups ($p = 0.00001$), with higher improvements in IG than in PG. The univariate analysis showed a significant improvement in lower limb range of motion with higher increase in IG than in PG. The main findings were the significant improvement in lunge and advance-advance lunge distance, maintaining with the same execution time. These results suggested that it is important to apply accentuated eccentric load on specific sport movements.

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

Introduction

Fencing is an open skill combat sport characterized by high intensity explosive actions and recovery periods. Elite fencers need higher explosive strength to accelerate the body over almost 600 milliseconds and travel around 1.4 m. Moreover, they need reactive strength to minimize their ground contact times and reach the maximum displacement speed in both concentric and eccentric modalities (Turner et al., 2014). Lower limbs' neuromuscular efficiency and proprioception, associated to biomechanical parameters, allow fencers to perform the technical movements from "*en garde"* position to lunge (Barth and Beck, 2007). Lunge in fencing can be improved by increasing the lunge length, the reaction time and the horizontal speed of the centre of gravity. The ability of a fencer to perform a long lunge is an effective factor for his /her success, particularly when coupled with high speed motion, which provides less chances for the opponent's reaction (Gholipour et al., 2008). Considering that speed and accuracy of movement have been demonstrated to be related to fencing performance (Guilhem et al., 2014), workouts consist in power and repeated change of direction training, in order to improve the fencing performance, largely characterized by eccentric contractions (Fiorilli et al. 2017).

Commonly fencers use the "repeat bout effect" of plyometric training to adapt the muscle system to eccentric loads (Attene et al., 2015). Plyometric training is a safe and feasible method for physical conditioning, which improves the neuromuscular function in young athletes (Bedoya et al., 2015). Traditionally, plyometric training is used to overload the eccentric phase of movements, stimulating the neural activation patterns during the stretch-shortening cycle (SSC). This training positively influences the intermuscular coordination, promoting greater excitability of the stretch reflex in muscle fibre mechanics, especially at the beginning of the concentric phase (Markovic and Mikulic, 2010; Piazza et al., 2014).

Nevertheless, it would be advisable to expose athletes to accentuated eccentric loads in specific conditions, i.e. using a rotary inertial device. The benefits of this kind of training are as follows. First, the use of this kind of device allows to benefit from the moment of inertia of a rotating flywheel to overload all phases of the athlete's movements (Núñez et al., 2017). During the athlete's concentric phase of movement (acceleration), a rope linked to the flywheel is fully wound off, storing energy in the system. In the eccentric phase (deceleration), by pulling the strap back onto the shaft, the system produces a resistance due to the tension of the traction rope, in response to the power applied, until the flywheel is brought to a stop. The optimal use of this device requires the athlete to apply the maximal effort during the acceleration phase. In fact, this device produces a resistance force (in the eccentric phase) which is proportional to that generated by the athlete's concentric effort. The flywheel technology, allows unlimited linear resistance loads during concentric and eccentric muscle actions, with the possibility of regulating the resistance loads in each repetition.

Secondly compared with the plyometric training,

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this kind of accentuated eccentric training leads to a prolonged eccentric strain, which might lead to a better adaptation. It appears that the exposure to prolonged eccentric training increases the eccentric kinetic energy and improves performance more than traditional methodologies (Tesch et al., 2017; Norrbrand et al., 2010).

Thirdly, the rotary inertial device applies its resistance in the same horizontal plan of the fencing technical movements are performed. In fact, this accentuated eccentric load may be applied directly on the specific technical elements, such as lunge and "*en garde*" position. The inertial force generated by the rotating cone-shaped flywheel, allows the athlete to freely move in the space directions (Fiorilli et al., 2020).

Lastly, the training load of this technology can be regulated also by adding the flywheel weights, generating a great eccentric effort, with a very low metabolic cost (Blazevich et al., 2007). It is well known that the energy needed to perform eccentric actions is about one fifth of the one required for concentric actions of the same cycle (Caruso and Hernandez, 2002).

Furthermore, it has been demonstrated that eccentric training is an effective method to improve lower limb range of motion (ROM) and that fencers need this skill to perform the technical movements without any limited ROM, such as lunge (Blazevich et al., 2007; O'Sullivan et al., 2012). A previous study identified a three-variable model for predicting lunge performance such as time to peak force, leg length, and flexibility (measured as the linear distance between the lateral malleolus of each leg during a split in the frontal plane). These characteristics accounting for 85% of the explained variance (Turner et al., 2014).

ROM It has been showed that the eccentric training promotes changes in ROM through an increased agonist voluntary activation and decreased antagonist coactivation (Pensini et al., 2002). Moreover, a prolonged eccentric phase of this training appears to be related to changes in the muscle length-tension curve (Aquino et al., 2010). Since the lower limb ROM has to be associated with fast strength gains, accentuated eccentric training could be recommended.

Therefore, the aim of the present study was to assess the effects of a 6-week training protocol, using a rotary inertial training device, on ROM, explosive and reactive strength, lunge and advance-advance lunge performances of young elite fencers. The study aimed also to assess the duration of the accentuated eccentric training residual effects, 6 weeks after the end of the training. It was hypothesized that athletes would take benefit adhering to a specific training based on accentuated eccentric loads used in similar conditions in which they train and compete.

Methods

Study design

The present study is a Randomized Controlled Trial designed to evaluate the effects of 6-weeks of accentuated Eccentric training with application of a rotary inertial device, on fencers' performance in comparison to traditional plyometric training of the same duration and volume. Before the start of the 6-weeks training, the same group performed two familiarization sessions to ensure that the appropriate technique was applied for each exercise. Fifty-four male foil fencers were randomly assigned either to Inertial Group (IG; n = 26), or to Plyometric Group (PG; n = 28). IG group carried out four exercises using a rotary inertial device and PG group carried out several plyometric exercises.

In order to evaluate the accentuated eccentric training residual effect duration, six weeks after the end of the intervention, the IG was tested for explosive and reactive strength and time and distance in executing the two fencing specific movements.

Participants

Fifty-four male foil fencers, competing at national level, were randomly assigned to the IG (n = 26) and the PG (n = 28). The PG served as control group. Sample and performance characteristics at baseline, referring to their competition period of training, are shown in Table 1.

For both groups, the randomization process was performed as follows: a progressive number was assigned to each of the 54 participants. Successively, a random number list (from 1 to 54 with no repeated numbers) was generated using an online software (https://www.random.org/sequences/, Dublin, Ireland). The list of participants was reordered according to the random number list and then participants were assigned to either IG or PG. Baseline homogeneity of the two groups was assessed after randomization. To be eligible for this study, fencers were required to meet the following criteria: to be free from joint injuries at the time of recruitment, to not make use of drug or other substances that could influence the correct execution of the tests and training exercises, and to have practiced fencing for almost five years. The athletes' usual training practice included five sessions per week, lasting approximatively 150 min. In the pre-competitive period the weekly training was as follows: for conditioning, one session of specific cardio training (medium load - RPE 5-6), one session of circuit training for maximal and explosive strength (high load - RPE 7-9), two sessions of plyometric and agility drills (high load) and one low load session of posture, balance and ROM training. In respect of technical and tactical training, fencers performed specific training for lower and upper limbs, with and without weapon, four times per week and a modelling session followed by a rest session. The athletes had no previous experience with the use of any type of flywheel device. After a detailed explanation about the aims, benefits, and risks involved in these experimental procedures, all participants and the parents of all the under-aged athletes gave their written informed consent. The study was designed and conducted in accordance with the Declaration of Helsinki and fully approved by the Bioethical Local Committee of University of Rome "Foro Italico" (University Committee for Research (CAR-IRB), Code: CAR 15/2019).

Table 1. Sample Characteristics at baseline. Data are means ±SD.

Variables	Inertial Group	Plyometric Group	Percentage Diffrences	*p* value *
Age	17.3 ± 1.9	17.6 ± 2.7	1.50	0.229
Height (m)	1.72 ± 0.08	1.73 ± 0.08	0.64	0.605
Age of experience	8.53 ± 2.33	8.67 ± 3.09	1.64	0.538
Session/week	4.76 ± 0.51	4.37 ± 0.77	-8.19	0.157
Weight (kg)	62.20 ± 10.21	64.23 ± 11.53	3.26	0.488
Dominant thigh (cm)	55.77 ± 4.75	55.18 ± 5.40	-1.06	0.665
Non-Dominant thigh (cm)	54.52 ± 4.20	54.42 ± 5.64	-0.18	0.943
Dominant calf (cm)	35.27 ± 2.33	35.47 ± 2.54	0.57	0.753
Non-Dominant calf (cm)	34.99 ± 2.78	35.38 ± 2.40	1.11	0.577
Inter malleolar distance (cm)	156.34 ± 12.47	152.43 ± 13.47	-2.50	0.264
Nordic break-point angle (°)	22.67 ± 7.26	18.18 ± 6.79	-19.81	0.075
Distance lunge with weapon (cm)	214.73 ± 22.90	223.52 ± 21.08	4.09	0.182
Distance lunge without weapon (cm)	216.19 ± 20.62	218.64 ± 23.03	1.13	0.707
Distance advance-advance lunge with weapon (cm)	377.10 ± 53.65	391.55 ± 40.45	3.83	0.306
Distance advance-advance lunge without weapon (cm)	370.24 ± 48.33	388.98 ± 32.95	5.06	0.129
Time lunge with weapon (s)	1.14 ± 0.15	1.04 ± 0.27	-8.77	0.141
Time lunge without weapon (s)	1.01 ± 0.21	0.96 ± 0.12	-4.95	0.353
Time advance-advance lunge with weapon (s)	1.70 ± 0.20	1.65 ± 0.17	-2.94	0.301
Time advance-advance lunge without weapon (s)	1.63 ± 0.18	1.61 ± 0.17	-1.23	0.694
Squat jump height (cm)	28.36 ± 6.35	27.42 ± 5.27	-3.31	0.617
Countermovement jump height (cm)	30.08 ± 6.48	29.53 ± 5.05	-1.83	0.766
7 repeated hopping contact time (s)	0.18 ± 0.03	0.19 ± 0.03	5.56	0.588
7 repeated hopping height (cm)	19.32 ± 7.70	20.26 ± 5.08	4.87	0.653

* computed with Anova One-Way.

Study procedures

At baseline, all the participants underwent a two-day testing session. In the first day session, anthropometric data were collected, and participants underwent a series of tests for the evaluation of adductor muscles' ROM, lower limb explosive and reactive strength and, in the second day, eccentric strength of the hamstring's muscles as well as time and distance in executing two fencing specific movements were evaluated. Participants were requested to avoid strenuous activities at least 48 hours before the baseline testing session.

After the baseline assessment, participants were randomly divided in two groups: IG and PG. Both groups performed 6-weeks training: IG performed their traditional training, replacing the plyometric traditional protocol with an inertial protocol, twice per week with a duration time of 60 minutes. The PG performed their traditional training maintaining the plyometric protocol with the same duration and volume of the IG flywheel protocol. At the end of the six weeks of training, the two groups were tested in the same way such as the baseline assessment.

In order to evaluate the duration of the residual flywheel effects, the IG was tested in respect of explosive and reactive strength and time and distance in executing the two fencing specific movements, six weeks after the end of the study. In this period IG the two groups performed usual fencing training.

Testing sessions

Anthropometric data

The anthropometric parameters included weight, height, thigh and calf circumferences of each participant. Body height was measured using a Harpender metal anthropometer to the nearest 0.1 cm; weight was measured with minimal clothing to the nearest 0.1kg with a medical electronic scale (A&D Instruments, Ltd, Abingdon, UK); body mass index (BMI) was calculated (BMI = kg/m2). For thigh and calf circumferences, a flexible calibrated tape was used, and measurements are recorded to the nearest 0.1cm. Three measurements were recorded and the mean values were used for the analysis.

Inter-Malleolar Distance test

Inter-Malleolar Distance test was measured, using a tape, between the medial malleoli when the supine athlete separates the lower limbs maximally with the knees straight and feet pointing straight up. This test accounts for 85% of the explained variance (Turner et al., 2014).

Explosive and reactive strength: Squat jump (SJ), Countermovement jump (CMJ) and 7- Repeated Hop (7R-HOP) tests

To evaluate lower limbs' explosive strength, athletes performed SJ, CMJ, and to evaluate reactive strength, 7R-HOP test was used, via 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 et al., 2011). Jumps height (cm) was estimated by flight time (s). In SJ and CMJ, participants were instructed to jump as high as possible, keeping hands on their hips (knee bent at 90°). The best of the three attempts (with two minutes' rest between each attempt) was considered for statistical analysis (di Cagno et al., 2008). Regarding 7R-HOP, the average height of the seven jumps (cm), with free arms, as well as the average contact time among the seven jumps (s), were considered for the analysis. A single attempt was performed. The test reliability between and within sessions is 0.40-0.90 and 0.87-0.98, respectively (Mok et al., 2016).

Eccentric strength of the hamstring's muscles: Nordic hamstring test

The Nordic hamstring test was used to evaluate the eccentric hamstring strength. The NORDIC test was performed following the procedures described by Lee et al. (2017) (eccentric method only) using a high-speed camera set at 300 fps (Exilim EX-F1, Casio Computer Co., Ltd., Tokyo, Japan). The NORDIC test break-point angle was measured as the angle between the line joining hip and knee at the beginning of the test (in vertical position), and to the point in which the participants could no longer resist the increasing gravitational force. Two attempts were performed with 5 minutes' rest between each attempt, and the best of the two scores was considered for statistical analysis.

Time required and distance covered in executing two fencing specific movements using the motion analysis

The motion analysis was used to analyze two fencing specific movements: lunge and advance-advance lunge, with the same high-speed camera used for NORDIC test. The camera Exilim EX-F1, was positioned in a static and defined point, in order to have the view of the athletes' forward and backward movements on the fencing platform, for a distance of 6 meters. Due to the resolution 512 x 384 at 300 fps, each pixel represented an area of ≃12 mm. Time and distance were computed using the software Kinovea (v.8.15, downloadable at https://www.kinovea.org/).

Lunge is the basic attacking movement. Starting to the *en garde* position, during the first phase of the lunge, the explosive contraction of the rear leg extensors produces the horizontal component impulses to move the centre of gravity forward, and the forward leg, coordinated with the rear leg, swings forward to improve the speed and distance of the lunge (Guilhem et al., 2014). The final phase ends with the forward foot contacting with the floor (Guan et al., 2018). The athletes were asked to perform the lunge movement trying to cover the maximum distance as fast as possible.

Advance-advance lunge, is a lunge preceded by two Advance movements. Advance is the basic movement used in fencing to step forward: it consists of a progression of the front foot followed by the rear foot such to maintain the same distance between the heels. Advance-advance lunge was used to simulate a basic attacking sequence in fencing. For each movement were considered: maximum distance covered with and without weapon, and time to execute the movement with and without weapon (Turner et al., 2014). Differences of execution with and without weapon could be expected on speed and amplitude of technical movements (Roi and Bianchedi, 2008)

The baseline tests were performed twice in two non-consecutive days in order to assess the reliability of each test, via test-retest.

Testing variables

The dependent variables, assessed in the previous tests, included: anthropometric variables as Weight, Dominant thigh circumferences, Non-Dominant thigh circumferences, Dominant calf circumferences, Non-Dominant calf circumferences; flexibility variable as Intermalleolar Maximum Distance; jump tests variables as Height of SJ test, Height of CMJ test, average height of the 7R-HOP test, average contact time of the 7R-HOP test; Motion analysis variables as NORDIC break-point angle, maximum distance covered without weapon in lunge movement, maximum distance covered with the weapon in lunge movement, time to execute lunge movement without weapon, time to execute lunge with the weapon, maximum distance covered without weapon in advance-advance lunge sequence, maximum distance covered with the weapon in advance-advance lunge sequence, time to execute advance-advance lunge without weapon, and time to execute advance-advance lunge with the weapon. To assess the reliability of the proposed variables, the Intra-class correlation coefficient (ICC) was calculated by test and retest performed at baseline. The ICC and 95%IC values were showed in Table 2.

The reliability of the test variables is considered good or excellent based on the classification suggested by Koo and Li (2016) (values less than 0.5 are indicate as poor reliability, values between 0.5 and 0.75 as moderate reliability, values between 0.75 and 0.9 as good reliability, values greater than 0.90 as excellent reliability). The reliability of weight, dominant thigh, non-dominant thigh, dominant calf, and non-dominant calf was not computed.

Table 2. Intraclass Correlation Coefficient (ICC) and 95% Confidence Interval (IC) of the variables.

Variables	ICC (2.2)	95% IC
Inter malleolar distance (cm)	0.981	0.968 – 0.989
Nordic_ break-point angle (degree)	0.959	0.931 – 0.976
Distance lunge with weapon (cm)	0.788	0.662 – 0.871
Distance lunge without weapon (cm)	0.792	0.668 – 0.873
Distance advance-advance lunge with weapon (cm)	0.948	0.912 – 0.970
Distance advance-advance lunge without weapon (cm)	0.939	0.898 – 0.964
Time lunge without weapon (s)	0.845	0.748 – 0.907
Time advance-advance lunge with weapon (s)	0.893	0.824 – 0.936
Time advance-advance lunge without weapon (s)	0.860	0.771 – 0.916
Squat height (cm)	0.763	0.576 – 0.871
Countermovement jump height (cm)	0.816	0.675 – 0.899
7 repeated hopping contact time (s)	0.908	0.831 – 0.950
7 repeated hopping_height (cm)	0.803	0.654 – 0.892

Table 3. Load increasing of the Accentuated Eccentric Training and Plyometric Training protocols.

Weeks	Accentuated Eccentric Training	Plyometric Training
1-2	3 rep. x 7sets; Rest 120" for each exercise (4)	1 x 7: Rest 120" for each exercise (2) 1 rep of 5 min-Circuit Training
3-4	4 x 7; Rest 120" for each exercise (4)	2 x 7; Rest 120" for each exercise (2) 1 rep of 5 min-Circuit Training
5-6	4 x 9; Rest 120" for each exercise (4)	3 x 7; Rest 120" For each exercise (2) 1 rep of 5 min-Circuit Training

Intervention description

Inertial Group protocol

Instead of their usual plyometric training, the IG, during the 6-weeks of the study intervention, performed two sessions per week of accentuated eccentric training using a rotary inertial device. "The Flyconpower conical machine" (Cuneo; Italy) was used to administer the experimental protocol. The cone-shaped shaft of this device has diameters of the base of 0.4 m and 0.1 m the vertex. Participants were attached to the flywheel device by a rope fixed at their waist. This condition allows the athlete to move freely in multiple-directions of the space.

After 8-12 min moderate intensity warm-up, including jogging, high knee skips, mobility exercises for hips, arms and trunk, lunges and backward lunges, submaximal repetitions of half-squat exercises, they performed the inertial training which consisted of two weekly sessions, with 72 hours of recovery between them, performing four typologies of exercises.

The workout intensity was estimated ex-post using the rate of exertion perception (RPE). The expected external load for each week ranged between 5-6 (values) using the Borg's Rate of Perceived Exertion scale CR-10 (RPE). It was expected that the eventual improvement of the explosive strength allowed the athlete to have this target RPE, corresponding to different increasing loads. The progressive increase of the load was showed in Table 3.

Accentuated eccentric training protocol:

Four typology of technical fencing exercises:

1. lunge with the rotary inertial device behind the athlete;
2. lunge with the device in front of the athlete;
3. advance advance lunge with the rotary inertial device behind the athlete;
4. advance advance lunge with the device in front of the athlete.

In the first exercise, athletes performed the lunge movement, keeping their back to the rotary inertial device. In the first part of the exercise, the athletes performed the lunge as fast as possible, and in the second part, they returned to the "*en garde*" position, resisting the force generated by the rotary inertial training device.

In the second exercise, the athletes were positioned in front of the device. They adopted the lunge position, with the body weight entirely carried on the front leg with the back leg extended. In the first part of the exercise, they had to transfer their body weight from the front leg to the back leg (they had to flex the back leg and to extend the front leg). In the second part of the exercise, they had to return to their starting position, resisting the force generated by the device (Figure 1).

In the third exercise, the athletes performed two steps forward, keeping their back to the device, and then they returned to their starting position performing two steps backwards.

In the fourth exercise, the athletes performed two steps backwards, with the device in front of them and then they returned to their starting position performing two steps forwards (Figure 2).

In both these last two exercises, the athletes were encouraged to perform the first two steps as fast as possible, and then to perform the other two steps in the opposite direction, resisting the force generated by the device. During the training, the athletes were encouraged to apply the maximum effort during the concentric phase, and then resist the force developed by the device during the eccentric phase.

Plyometric group protocol

The PG, during the 6-weeks of the study, performed their traditional weekly training including a plyometric protocol, which was carried out at the same time in which the IG performed the accentuated eccentric training. The PG performed the same warm-up protocol of IG, and then they performed the plyometric protocol which consisted of three types of exercise, twice per week, with 72-hour rest period between the two plyometric training days. The contents and the progressive increase of the load was showed in Table 3. The expected external load for each week ranged between 5-6 (values) using the Borg's Rate of Perceived Exertion scale CR-10 (RPE).

Plyometric training protocol:

1. Set of drop jumps from 50 cm boxes;
2. Set of jumping lunges and a set of squat lunges;
3. **Circuit training contents:**
   - a set of multiple stiffness jumps with both legs (unilateral and bilateral) in different directions,
   - a set countermovement jumps, jump onto 50 cm box,
   - a set of front hurdles jumps with and without knee bending,
   - speed ladders exercises as forward to feet each hole and forward carioca speed drills.

Statistical analysis

The Chi-squared test for normality and the Levene test to assess the equality of variances were used in respect of the Assumptions for the parametric test. At baseline, the analysis of variance (ANOVA) showed the samples' homogeneity, with regard to the anthropometric measures, gender, and pre-tests scores of Jump tests, NORDIC test, and motion analysis.

After the training protocols, the differences between the post-tests and the pre-tests scores were calculated (Δ

Score = post-test scores - pre-test scores). Two multivariate Analyses of Variance (MANOVA) were performed to evaluate significant differences between the two groups (IG vs. PG), relatively to the Δ Score.

The first MANOVA was performed on the 6 anthropometric variables, whereas the second MANOVA was performed on the 13 performance scores of the jump tests, NORDIC test, and motion analysis of lunge and advance-advance lunge.

The results of the IG protocol residual effects were compared to the IG post-test results, using a Repeated Measures Multivariate Analysis of Variance (RM-MANOVA), in order to verify the durability over 6 weeks of the results of the jump tests (SJ, CMJ and 7R-HOP tests) and the results of the motion analysis of lunge and advance-advance lunge. All the variables were included in RM-MANOVA.

For all the analyses, a value of $p<0.05$ were considered as statistically significant. Furthermore, partial eta squared values (η^2p) were computed for all the analysis, as indicator of the effect size. A partial eta-squared value between 0.01 and 0.06 indicates a small effect size, and partial eta-squared between 0.06 and 0.13 indicates a medium effect size, whereas a value equal or higher than 0.14 indicates a large effect (Cohen, 1988). SPSS (IBM, v.24, Chicago, IL, USA) ad Excel 365 (Microsoft, v.2004, Redmond, WA, USA) were used for statistical analyses.

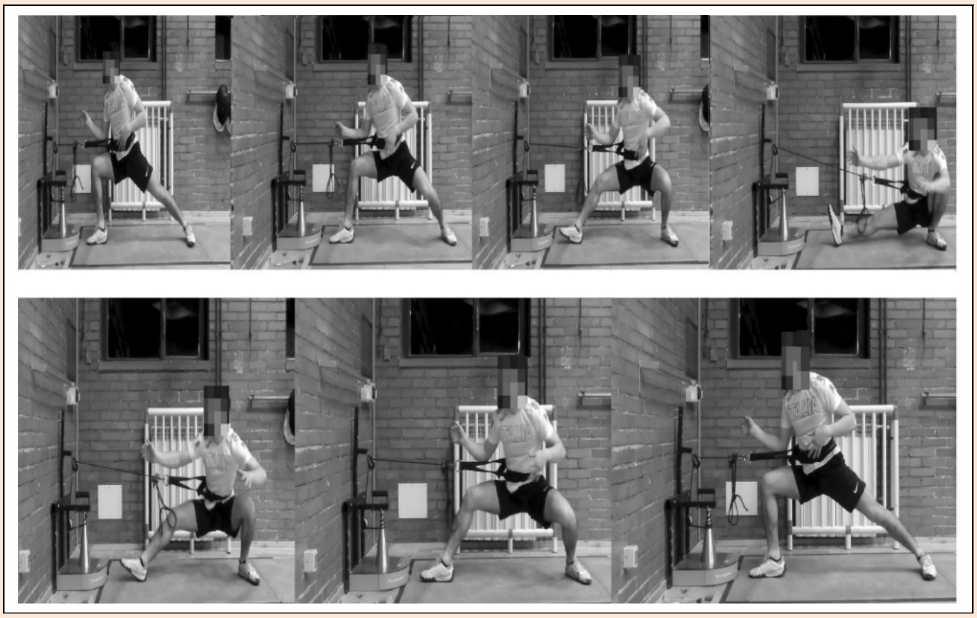

Figure 1. Rotary inertial device applied to a fencing technical movement. Phase I: the athlete had to transfer his body weight from the front leg to the back leg. Phase II: the athlete had to return to his starting position.

Figure 2. Rotary inertial device applied to a fencing technical movement. Phase I: the athlete performed 2 steps backwards. Phase II: the athlete returned to his starting position performing 2 steps forwards.

Table 4. Results of anthropometric measures and performance tests after the intervention. Data are means ± SD.

Variables	Groups	PRE	POST	Average Δ Score	*p* value (*η2p*)
Weight (kg)	IG	62.20 ± 10.21	62.97 ± 10.36	0.77	0.788
	PG	64.23 ± 11.53	64.89 ± 10.71	0.66	(0.001)
Dominant thigh (cm)	IG	55.77 ± 4.75	56.22 ± 4.96	0.46	0.641
	PG	55.18 ± 5.40	55.41 ± 5.00	0.24	(0.004)
Non Dominant thigh (cm)	IG	54.52 ± 4.20	55.09 ± 4.35	0.57	0.220
	PG	54.42 ± 5.64	54.38 ± 4.95	-0.04	(0.028)
Dominant calf (cm)	IG	35.27 ± 2.33	35.37 ± 2.34	0.10	0.576
	PG	35.47 ± 2.54	35.47 ± 2.44	-0.01	(0.006)
Non Dominant calf (cm)	IG	34.99 ± 2.78	35.43 ± 2.44	0.43	0.216
	PG	35.38 ± 2.40	34.38 ± 6.40	-1.00	(0.028)
Inter malleolar distance (cm)	IG	156.34 ± 12.47	162.96 ± 10.17#	6.62	0.031*
	PG	152.43 ± 13.47	156.03 ± 13.48#	3.60	(0.084)
Nordic break-point angle (°)	IG	22.67 ± 7.26	24.88 ± 6.52#	2.21	0.528
	PG	18.18 ± 6.79	21.55 ± 5.69#	3.36	(0.009)
Distance lunge with weapon (cm)	IG	214.73 ± 22.90	252.62 ± 25.00#	37.90	0.00002*
	PG	223.52 ± 21.08	233.98 ± 27.07#	11.69	(0.346)
Distance lunge without weapon (cm)	IG	216.19 ± 20.62	248.63 ± 23.85#	32.44	0.006*
	PG	218.64 ± 23.03	236.59 ± 27.53#	17.95	(0.161)
Distance advance-advance lunge with weapon (cm)	IG	377.10 ± 53.65	434.75 ± 54.38#	57.64	0.00001*
	PG	391.55 ± 40.45	402.10 ± 37.24	10.55	(0.374)
Distance advance-advance lunge without weapon (cm)	IG	370.24 ± 48.33	436.93 ± 58.40#	66.69	0.00005*
	PG	388.98 ± 32.95	406.20 ± 45.32#	17.22	(0.316)
Time lunge with weapon (s)	IG	1.14 ± 0.15	1.07 ± 0.23	-0.07	0.063
	PG	1.04 ± 0.27	1.14 ± 0.22	0.10	(0.076)
Time lunge without weapon (s)	IG	1.01 ± 0.21	0.93 ± 0.19	-0.08	0.437
	PG	0.96 ± 0.12	0.94 ± 0.14	-0.03	(0.014)
Time advance-advance lunge with weapon (s)	IG	1.70 ± 0.20	1.67 ± 0.20	-0.03	0.490
	PG	1.65 ± 0.17	1.67 ± 0.16	0.02	(0.011)
Time advance-advance lunge without weapon (s)	IG	1.63 ± 0.18	1.60 ± 0.25	-0.03	0.998
	PG	1.61 ± 0.17	1.58 ± 0.19	-0.03	(<0.001)
Squat height (cm)	IG	28.36 ± 6.35	31.46 ± 6.88#	3.10	0.101
	PG	27.42 ± 5.27	29.09 ± 5.46#	1.67	(0.060)
Countermovement jump height (cm)	IG	30.08 ± 6.48	33.39 ± 8.5#	3.49	0.048*
	PG	29.53 ± 5.05	30.71 ± 4.92	1.18	(0.089)
7 repeated hopping contact time (s)	IG	0.18 ± 0.03	0.20 ± 0.04#	0.02	0.262
	PG	0.19 ± 0.03	0.20 ± 0.03#	0.01	(0.028)
7 repeated hopping height (cm)	IG	19.32 ± 7.70	25.55 ± 4.63#	6.23	0.095
	PG	20.26 ± 5.08	23.49 ± 5.36#	3.24	(0.062)

* Significantly different in the comparison Δ Scores of the IG vs. the Δ Score of the PG.
# Significantly different (at least p <0.03) in the comparison PRE vs. POST (for each group analyzed separately).

Results

The results are reported as mean ± Standard Deviation (SD). Chi-squared and Levene tests, showed that the assumptions to perform parametric tests were not violated.

The MANOVA performed on the anthropometric measures did not show significant differences between the two groups ($F_{6,47}$ = 1.348; p = 0.255; η^2p = 0.147). The univariate analysis showed a significant difference in the Inter Malleolar Distance variable with a higher improvement obtained by IG (Table 4).

The MANOVA performed on the performance scores showed significant differences between the two groups ($F_{13,40}$ = 5.760; p = 0.00001; η^2p = 0.674), with the IG that have obtained significant higher results in several tests (Table 4).

The RM-MANOVA performed on IG post-test *vs.* 6-weeks after training (AT; for 22 participants), did not show significant differences after the interruption of the training ($F_{12,10}$ = 2.472; p = 0.081; η^2p = 0.748). Only 22 of the 26 IG participants performed the last test because of concomitant involvement in competitions (Table 5).

Discussion

In this study a flywheel cone-shaped inertial device was applied directly on young fencer elite athletes while performing two specific technical elements, lunge and advance-advance lunge, providing an accentuated eccentric load training. The device was used both in front and behind of the athlete: applied in front of the athlete, it overloaded the lower limb muscles in the phase of returning *"en garde";* behind the athlete, the propulsive phase of assault was overloaded. The possibility of the rotary inertial device to apply resistance to multidirectional movements (forward, backward and lateral), in different joint angles, increasing the muscles' time under tension, warrants improvement more than a conventional fencing training.

Table 5. Comparison between the results of IG Post-tests vs. 6-weeks after the intervention (AT). Data are means ±SD.

Variables	POST	6 WEEKS AT	Average Δ Score	*p* value (η^2p)
Distance lunge with weapon (cm)	251.41 ± 25.79	254.07 ± 20.37	2.66	0.513 (0.021)
Distance lunge without weapon (cm)	246.86 ± 24.16	249.34 ± 21.9	2.48	0.508 (0.021)
Distance advance-advance lunge with weapon (cm)	429.08 ± 52.62	427.82 ± 56.73	-1.26	0.873 (0.001)
Distance advance-advance lunge without weapon (cm)	431.22 ± 56.41	434.29 ± 52.18	3.08	0.668 (0.009)
Time lunge with weapon (s)	1.06 ± 0.24	1.08 ± 0.22	0.03	0.267 (0.058)
Time lunge without weapon (s)	0.92 ± 0.19	0.94 ± 0.18	0.01	0.651 (0.010)
Time advance-advance lunge with weapon (s)	1.68 ± 0.21	1.69 ± 0.22	0.01	0.747 (0.005)
Time advance-advance lunge without weapon (s)	1.59 ± 0.26	1.60 ± 0.23	0.01	0.860 (0.002)
Squat height (cm)	30.04 ± 5.57	30.12 ± 6.08	0.08	0.892 (0.001)
Countermovement jump height (cm)	32.04 ± 7.45	31.47 ± 6.05	-0.57	0.489 (0.023)
7 repeated hopping contact time (s)	0.21 ± 0.04	0.20 ± 0.03	-0.01	0.257 (0.061)
7 repeated hopping height (cm)	25.3 ± 4.61	21.55 ± 5.66	-3.57	0.000* (0.487)

* Significantly different but the overall RM-MANOVA indicate a non-significant modification of the results.

The cone-shaped device, used in this study, offers less resistance to the athletes' movements, considering that the participants of this study had not so much experienced in this training methodology. The cone-shaped inertial device allows to a greater acceleration in the concentric phase and an easier deceleration in the eccentric phase, comparing to a horizontal axis cylinder-shaped inertial device.

Six week-eccentric training resulted effective to improve the fencers' ROM, as demonstrated in Inter Malleolar Distance improvement, as well as the distance covered in both lunge and advance-advance lunge. A good ROM allowed to cover a significantly greater distance during lunge (Gutierrez-Davila et al., 2014).

The main finding of this study was in fact a significant improvement in lunge and advance-advance lunge amplitude, maintaining the same execution time, after the accentuated eccentric training using this rotary inertial device. Even if no significant differences were found, after the intervention, in IG pre and post execution time, during the two forms of lunge, the IG covered a significant longer distance, than in the pre-test. We consequently presumed an improvement in the speed of movement. In fencing performances, both the maximum forward acceleration and the capacity to decelerate the body mass as quickly as possible, are fundamental determinants of performance. The ability to quickly arrest the athlete, reducing the required knee flexion, may reduce the transition time to change direction and return to on-guard position (Turner et al., 2014). Previous study showed that accentuated eccentric training improves eccentric speed and eccentric kinetic energy of performance (Gonzalo-Skok et al., 2016). Moreover, the absence of knowledge of the eccentric load magnitude applied by the flywheel device, may has stimulated different adaptations of the athlete's neuromuscular system and coordination (di Cagno et al., 2014). Since fencing is characterized by uncertainty of loads (Gutiérrez-Dávila et al., 2014), athletes could take benefit by adhering to training with flywheel device, which apply stressors in similar conditions in which they train and compete.

Another result was that the lunge and advance-advance lunge amplitude of the IG were significantly better than those obtained by the PG. This result could be explained by the specificity of the proposed eccentric exercises, considering that the efficacy of a training method in improving ROM is strictly related to the ROM degrees at which the muscles are stressed (Blazevich et al., 2007). The IG intervention effectiveness in improving the performance variables is also supported by the excellent value of effect size, obtained by the MANOVA, performed on performance variables (η^2p = 0.674). This value indicates that IG intervention obtained a high magnitude in score changes. A previous study pointed out that the exercise protocols with accentuated eccentric loads warrant greater strength improvements than those in which load is constant during both the concentric and eccentric phases (Suarez-Arronez et al., 2018).

The results of Inter Malleolar Distance test highlighted that IG improved ROM more than PG. It has been showed that the eccentric training promotes changes in ROM through an increased agonist voluntary activation and decreased antagonist coactivation (Pensini et al., 2002). Eccentric training is effective to improve lower limb ROM (Duclay et al., 2009).

No significant differences in the execution with and without the weapon were found. In elite athletes, having high degree of skills, the two different conditions did not affect the efficacy and coordination of the movement pattern (Nyström et al., 1990).

After both the two training protocols, fencers improved their lower limb explosive and reactive strength. Fencers need a great extensor muscles' strength: in the rear leg to perform efficient propulsive phases, while in the front leg to decelerate the body during the last braking phase of the assault (Nyström et al., 1990). The better adaptations induced by training using a rotary inertial device are explained by the powerful stretch reflex produced in the eccentric-concentric transition. The prolonged eccentric exposure and the brief-high SSC activity, promoted by rotary inertial device, improved not only the eccentric action, but also the successive concentric contraction (Cormie et al., 2010). It was assumed that the explosive strength improvements were due to the intensity and duration of the muscular tension, resulting in longer contraction periods, according to the stimulus-tension theory (Crewther et al., 2005). Regarding specifically the reactive strength, which is considered the preferred indicator to assess the SSC ability in fencers (Flanagan, 2008), the improvement was probably due to changes in the stiffness of the elastic elements of the muscle-tendon complex and to the motor unit recruitment enhancement (Fiorilli et al., 2017; Maroto-Izquierdo et al., 2017). Higher values of leg stiffness may provide the ability to minimize lead foot ground contact time in fencing technical movements' execution. The lead food contact time is a function of quadriceps' eccentric strength, which unloads the ankle muscles (Trautmann et al., 2011).

The effectiveness of Plyometric training in this study was increased by including, for the assessment, several training exercises (e.g. dropping jump), similar in their motor pathways to the chosen test. The specificity of training-related mechanism could explain the high effectiveness of the plyometric training in these tests (Mooses et al., 2015).

Significant difference was found between groups for CMJ, in which IG obtained better results, probably due to an increased storage and release of energy, available at the end of the eccentric phase in the inertial training (Maroto-Izquierdo et al., 2017). CMJ and SJ were identified as strong predictors of efficient Lunge since maximum strength and power determine an optimal Time Peak of Force in Lunge (Young, 1995).

Both groups improved eccentric hamstring strength. The accentuated eccentric training, elicits the hamstring eccentric strength, increasing the optimal force-length relationship (English et al., 2014). Guilhem et al. (2014) showed that hamstring muscles of the rear leg are more solicited to produce a maximal anteroposterior velocity during fencing assault. Nordics and stiff-leg deadlifts can help to reduce the high incidence of hamstring strains in fenceing and, increasing adductor flexibility, enhance Lunge distance (Turner et al., 2014)

The retention of the adaptation, promoted by plyometric training, is widely studied in previous researches (Santos and Janeira, 2011). No studies assessed the residual effects of the flywheel eccentric training. In the present study the IG maintained the performance gains for six-weeks after the end of the accentuated eccentric training. The longer lasting effects were guaranteed by the specific aspects of training and the slow eccentric execution (Hakkinen, 1981). The expected detraining of stiffness, assessed by 7R-HOP test, was confirmed by the present data (Colliander and Tesch, 1992).

No significant differences in anthropometric measures were found. To obtain body composition adaptations, more than 6 weeks of high intensity strength training are needed (Franchini et al., 2019).

Conclusion

The loaded eccentric contractions, guaranteed by the flywheel device application, are an effective powerful stimulator for the last braking phase of the lunge, both ensuring the movement amplitude, and increasing the leg extensor strength (O'Sullivan et al., 2012; Frère et al., 2011). The possibility of the rotary inertial device to apply resistance to multidirectional movements, in different joint angles, has increased the muscles time under tension, both in concentric and eccentric phase of movements, promoting better adaptations than those of a conventional fencing training. These findings suggested that it is important to specifically apply accentuated eccentric load on sport movements, soliciting intermuscular coordination patterns, in order to maximize the transfer in the successive fencing performance. It would be recommended to expose fencers to an accentuated eccentric training in specific conditions, applying a cone-shaped flywheel device. Given that both lower limbs are solicited on wide-ranging, directly during fencing movements, this kind of training could represent a potential mean for practical application in fencing training (Guilhem et al., 2014). Moreover, this training modality, as a variation of training means, could be recommended for young fencers.

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Key points

- Eccentric training, applied by a flywheel device, resulted effective at improving flexibility.
- Flywheel device application promotes muscle contraction for a longer time under tension.
- The Inertial training allows to transfer the eccentric load effects to the real sport performance.
- The lack of the load knowledge, using the flywheel device, may stimulate the athlete coordination.

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