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Research article

Impact of Weekly Eccentric Overload Training on Locomotor and Mechanical Performance in Youth Soccer Players

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Abstract
This study examined the impact of weekly eccentric overload training (EOT) on locomotor and mechanical performance during small-sided games (SSGs) in elite youth soccer players. A total of 22 elite male youth soccer players participated in this study. A controlled, non-randomized study design was employed. Players were assigned to either an eccentric overload training group (EOT, n = 9) or a control group (CON, n = 13). The EOT group incorporated one additional eccentric training session into their regular regimen, while the control group maintained their standard training schedule throughout the 8-week study. The Eccentric Overload Training (EOT), known for its benefits in injury prevention and performance enhancement, incorporated five exercises using flywheel devices: K-box squats, split squats, dynamic forward and backward lunges, and unilateral hamstring kicks on the Versa-Pulley. A total of 1,117 small-sided game (SSG) observations were analyzed (EOT = 528, CON = 589). No significant differences were found in locomotor variables, including zScore for total distance covered (TD), high-speed distance (HSD), very high-speed distance (VHSD), and sprint distance (SD). However, the intervention group showed lower acceleration (ACC) and deceleration (DEC) compared to controls ($p < 0.05$). Player load (PL) varied significantly between groups and over time ($p < 0.05$). These findings suggest that incorporating a weekly eccentric overload training (EOT) session may enhance locomotor performance despite temporary reductions in mechanical performance in elite youth soccer players. The practical application of the study is that minimal preventive eccentric work can be added into the intervention process without compromising physical performance capacity during that period.

Key words: Team sport, time-motion, training tasks, external training load.

Introduction

Small-sided games (SSGs) are widely used in soccer training to improve players' technical, tactical, and physical skills (de Dios-Álvarez et al. 2024). SSGs involve modified games with reduced field dimensions, adapted rules, and fewer players, making them effective for player development (Hill-Haas et al., 2011). Based on previous scientific research, the physical performance and the emergence of fatigue during SSGs depending on multiple factors. Hence, a large number of variables can be manipulated according to the aim of each session (Lorenzo-Martínez et al., 2020). In consequence, this type of tasks has been progressively growing in terms of their application during training process in amateur (de Dios-Álvarez et al., 2024) and professional soccer teams (Riboli et al., 2023), both in male and female players (de Dios-Álvarez et al., 2022).

Various resistance training methods have been employed to enhance athletic performance, including eccentric-overload training (EOT) (Morris et al., 2022). In recent years, inertial eccentric-overload training programs using flywheel devices have gained significant popularity, particularly among team sport athletes and soccer players (de Hoyo et al., 2016). Flywheel inertial devices create resistance by spinning a disc or cone, leading to increased muscle activation during the eccentric phase compared to free weights (Norrbrand et al., 2010). The force applied unwinds a connected strap, causing the device to rotate. After completing the concentric phase, the strap rewinds, requiring the individual to resist the pull of the rotating flywheel through eccentric muscle action (Beato et al., 2024).

Incorporating inertial EOT as an alternative or addition to traditional training methods offers potential benefits for soccer players, such as improved sprint performance and enhanced change of direction, by providing a more specific training stimulus that allows athletes to move freely in three dimensions (Núñez et al., 2017). Moreover, this training method enhances both coordination and muscular architecture (Friedman-Bette et al. 2010; Gérard et al. 2020), fostering the development of stronger and faster muscles, thereby improving strength, speed in linear sprints (Buonsenso et al., 2023), and agility in change of direction actions (de Hoyo et al., 2016; Liu et al., 2020). Moreover, it offers a reduction in muscle injury incidence and severity (Askling et al., 2003; de Hoyo et al., 2015). A study, conducted with handball players, demonstrated that adding a weekly EOT improved jump and strength performance (Sabido et al., 2017). Specifically, with young soccer players, de Hoyo et al. (2015) showed that a 10-week in season eccentric-overload training was effective to improve jump and sprinting abilities. Previous studies have demonstrated that EOT can significantly improve change of direction ability (de Hoyo et al., 2016), lower-limb muscle contractile function (Beato et al., 2021), and enhance sprint performance and half-squat power output over a full season (Suárez-Arrones et al., 2018), there remains a critical gap in understanding how EOT specifically affects locomotor and mechanical performance during SSGs.

Numerous training articles have examined the effects of strength training on neuromuscular fitness and performance in soccer players. Hence, the effects of SSGs on strength-performance variables in soccer players have been previously analyzed (Nayıroğlu et al., 2022; Young and Rogers, 2014). Recently, Arslan et al. (2021) demonstrated

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that combining SSG and core training could be highly beneficial for fitness performance. In addition, a more recent study combining SSGs and strength training also showed beneficial effects in neuromuscular fitness (Querido and Clemente, 2020). However, the reciprocal effects of strength training on performance within SSGs game scenarios remain largely unexplored. To the best our knowledge, only a study involving female soccer players has investigated the influence of eccentric strength training on metrics such as the number of accelerations and decelerations during small-sided games (Nevado et al., 2021). These authors demonstrated that 10 sessions of EOT throughout five weeks improved the neuromuscular performance during the SSGs.

In the practical context of soccer training, time constraints often limit opportunities for strength training, especially during the in-season period. Despite this, strength training remains crucial for performance enhancement and injury prevention, making it essential to understand the effects of incorporating a weekly EOT session on player performance. While SSGs are widely used to replicate match demands, limited research has examined how supplementary strength interventions, such as EOT, influence locomotor and mechanical responses in game-like scenarios. Investigating these effects in elite youth players is especially relevant, as their physiological and neuromuscular characteristics are still maturing. To address this gap, this study used SSGs as a practical setting to evaluate the impact of weekly EOT on locomotor and mechanical performance metrics, providing insights into the potential adaptations in elite youth soccer players within real-game contexts.

Therefore, the aim of this study was to investigate the influence of integrating a weekly EOT session on locomotor and mechanical performance, while respecting the validity of assessing it through the SSGs, in young elite football players. The starting hypothesis is that a progressive increase in the implementation of two EOT sessions should not affect the locomotor and mechanical performance of the players. Results of no effect on game performance would allow to know the minimum dose that allowing the addition of preventive work in training would not compromise physical performance in the tasks played during the week and consequently in competition.

Methods

Participants

The data for this study were collected from players belonging to an elite Spanish soccer academy (n = 22; age = 17.1 ± 0.6 years; height = 175.1 ± 5.9 cm; body mass = 68.2 ± 4.6 kg and body fat percentage = 10.2 ± 0.8 %). The participants competed at the highest competitive level for their age group. The body fat percentage was measured using skinfold caliper post-intervention. Goalkeepers were excluded from the data collection. The club's medical staff verified the health status of each player. An 'injured' player was defined as one who was unable to participate in regular team training due to any injury or medical condition, including musculoskeletal injuries (e.g., sprains, strains), bone injuries, or other relevant health issues, whether acute or chronic. Additionally, players diagnosed with injuries by medical staff or those undergoing rehabilitation sessions were also excluded from the data collection. The training protocols were known and had been practiced by all participants prior to the research. Players were instructed to maintain normal daily food and water intake. A consent letter was obtained from the club agreeing with the procedures. The local Ethics Committee (10–0721) approved the study and it was performed in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from participants and legal representatives.

Study design

Using a non-randomized, controlled study design, participants were assigned to eccentric overload training (EOT = 9; age = 17.2 ± 0.4 years; height = 175.8 ± 6.9 cm; body mass = 69.2 ± 4.1 kg and body fat percentage = 10.3 ± 0.9 %) or control group (CON = 13; age = 17.0 ± 0.7 years; height = 174.5 ± 5.3 cm; body mass = 67.4 ± 5.0 kg and body fat percentage = 10.1 ± 0.8 %). Randomization was not feasible in this study due to training schedules and logistical constraints. All players belonged to the same team and carried four or five weekly 90-minute field training sessions compounded by warm-up, technical actions, small, medium, or large sided games along tactical activities. In addition to field training sessions with the team, participants in the eccentric group performed a weekly session of eccentric overload training throughout the duration of the study. All players in the EOT group completed at least 80% of the prescribed sessions (a minimum of seven sessions). Compliance was monitored through regular check-ins and direct observation during training sessions to ensure adherence to the intervention protocol. Meanwhile, the control group was limited to carrying out the usual training sessions programmed for the whole group by the technical staff. The regular training was equated between both groups in terms of volume (average: 61.1 ± 21.0). Before the intervention, both groups (Control and Intervention) showed no significant differences in their physical test results. In the Countermovement Jump (CMJ), the Control group achieved 38.3 ± 4.4 cm, while the Intervention group reached 36.4 ± 5.1 cm ($p = 0.393$). Similarly, in the Squat Jump (SJ), the Control group recorded 37.8 ± 3.6 cm, and the Intervention group 36.4 ± 5.6 cm ($p = 0.511$). For the Intermittent Fitness Test (VIFT), the Control group reached 21.8 ± 0.9, while the Intervention group scored 22.3 ± 0.9 ($p = 0.225$). Finally, in the 20m Sprint, both groups showed identical performance, with times of 3.1 ± 0.1 s ($p = 0.779$).

Eccentric training intervention

The first experimental group executed eight EOT sessions. The training consisted of five exercises using flywheel devices; Kbox squat, Kbox split squat (kBox 3, Exxentric AB TM®, Bromma, Sweden), dynamic forward lunges, dynamic backward lunges and unilateral hamstring kicks in Versa-Pulley (IberianSportTech, Sevilla, Spain). The unilateral exercises were performed twice, one with each leg. During the training, the players were encouraged to perform the concentric phase as fast as possible, while delaying the braking action to the last third of the eccentric phase (Sabido et al. 2017). Following previous studies (Tous-Fajardo et al. 2016), the training program was increasing progressively. The volume was increased as follows: 2 sets × 6 repetitions in the first week; 3 sets × 6 repetitions in weeks 2 and 3; 3 sets × 8 repetitions in weeks 4 to 7; and 4 sets × 8 repetitions in week 8 (Table 1). The intensity of the eccentric-overload training was controlled by adjusting the flywheel inertia settings for each exercise, with repetitions ranging from 6 at 0.025 kg·m² to 8 at 0.05 kg·m², progressively increasing over the eight-week study period. Additionally, the number of weights on the cone base was adjusted to further increase gradually the intensity (ranging from 4 to 10 weights), based on the requirements of each exercise (Table 1). Between exercises and sets, a minimum of 30 sec and one min of passive recovery was provided, respectively (Tous-Fajardo et al., 2016).

Small-Sided Games

A total of 1117 SSGs' individual observations were undertaken (average per player: 50.8 ± 20.0) and all SSGs were grouped according to the ApP (EOT, n = 528 observations, and CON, n = 589). SSGs ranged from 10 vs 10 to 1 vs 1 and ApP ranged from 35 to 460 m^2 per player. The SSG training formats, described in Table 2, were designed and implemented solely by the team's technical staff, as the authors did not have the opportunity to propose any SSGs. Goalkeepers were excluded in the calculations. The SSGs were performed under the supervision and motivation of several members of the technical staff to maintain a high work ratio. In addition, a ball was immediately made available by replacement when it went out of play. In SSGs, the corners were replaced by a ball in game from the goalkeeper (de Dios-Álvarez et al. 2024). SSGs were registered four weeks before intervention, eight weeks during intervention and three weeks after intervention. In total 15 weeks were analyzed (Table 3).

External load

The running variables were obtained from the Global Positioning System (GPS). All external load measures were normalized as relative distance covered in one minute ($m \cdot min^{-1}$) or the number of accelerations in one minute ($n \cdot min^{-1}$) (de Dios-Álvarez et al. 2023). Consistent with a previous study that utilized similar thresholds (de Dios-Álvarez et al. 2024), the activity demands were reported with the following locomotor variables: total distance (TD), high-speed (>18 $km \cdot h^{-1}$) distance (HSD), very high-speed (>21 $km \cdot h^{-1}$) distance (VHSD) and sprint (>24 $km \cdot h^{-1}$) distance (SD). Regarding mechanical measures: number of high-intensity (>3 $m \cdot s^{-2}$) accelerations (ACC), number of high-intensity (< -3 $m \cdot s^{-2}$) decelerations (DEC), and player load (PL) were taken into account. This last metric is a measure based on the tri-axial accelerometer measures and may serve as a complementary tool for measuring the load from activities misrepresented by time-motion analysis (Bredt et al. 2020).

Two strategies were implemented to make possible the comparison of the response given by the players in the SSG. First, the values relative to min of practice were calculated, as the SSGs had different durations. Also, all external load measures were transformed into zScore values for a more precise analysis. The zScore transformation was used to determine whether a player's external load values were above or below the distribution mean. A negative zScore indicated a potentially concerning condition, reflecting a reduction in the external load measure, while a positive zScore reflected an increase in the external load relative to the player's average for the corresponding SSGs.

Procedure

Data were collected over a four-week period (February to March 2023) preceding the 8-week intervention (March to May 2023) and during the three weeks (May 2023) following the intervention (Post-Intervention). In the first week, prior to the commencement of the intervention, participants were provided with a comprehensive explanation of the experimental protocol and relevant recommendations.

Regarding field training sessions, the participants undertook their traditional weekly training routine. All training sessions were performed on artificial pitches and all training sessions were scheduled at the same time (16:30-18:45). During training sessions, players' movements were recorded using a portable 10 Hz GPS device that also incorporates a 400 Hz tri-axial accelerometer (Fitogether®, Inc, South Korea). Acceleration activity was measured as a change in speed for a minimum period of 0.5 seconds with acceleration at least of 2 $m \cdot s^{-2}$. These GPS devices seem to be valid and reliable for use in team sports (Scott et al. 2016; Nikolaidis et al., 2018). Moreover, similar devices were used in previous research with soccer players during SSGs (de Dios-Álvarez et al., 2024). The GPS device was attached to the upper back of each player by means of a special harness, and according to the manufacturer's instructions, all GPS units were activated 10 minutes before the training sessions began.

Table 1. Chronology and description of eccentric training methodology.

Week	# session	Sets	Repetitions	Workload		
				Split Squat and Squat in Kbox ($Kg \cdot m^{-2}$)	Forward and Backward Lunges	Hamstring kicks
1	1	2	6	0.025	8 out 12	4 out 12
2	1	3	6	0.025	8 out 12	4 out 12
3	1	3	6	0.025	8 out 12	4 out 12
4	1	3	8	0.025	8 out 12	4 out 12
5	1	3	8	0.025	8 out 12	4 out 12
6	1	3	8	0.05	8 out 12	4 out 12
7	1	3	8	0.05	10 out 12	8 out 12
8	1	4	8	0.05	10 out 12	8 out 12

Inertia settings for each exercise, ranging from 0.025 kg·m² to 0.05 kg·m². Additionally, the number of weights on the cone base was adjusted ranging from 4 to 10 weights.

Table 2. Description about small sided games procedure.

Format	Length and Width ratio	Outcome	Type and number of goals	Use and Number of floater	Observations	Rules
1 v 1	23 x 22	GK	Big goals & 2	No	10	No offside rule was applied The balls were replaced from goals (if there was) Verbal encouragement or feedback was allowed from coaches throughout the task The neutral player (if there was) was always playing with the team in possession of the ball
2 v 2	18 x 18	GK	Big goals & 2	No	8	
	23 x 22	GK	Big goals & 2	No	10	
3 v 3	26 x 20	GK	Big goals & 2	No	30	
4 v 4	23 x 22	GK	Big goals & 2	No	13	
	28 x 23	GK	Big goals & 2	No	13	
5 v 5	32 x 25	GK	Big goals & 2	No	28	
	32 x 28	GK	Big goals & 2	Yes & 2	16	
6 v 6	32 x 28	GK	Big goals & 2	Yes & 3	14	
	32 x 32	GK	Big goals & 2	Yes & 6	48	
	32 x 40	GK	Big goals & 2	Yes & 4	40	
7 v 7	40 x 40	GK	Big goals & 2	Yes & 2	14	
	62 x 64	GK	Big goals & 2	Yes & 1	6	
8 v 8	28 x 20	P	No	Yes & 4	17	
	28 x 28	P	No	Yes & 2	13	
	50 x 40	GK	Big goals & 2	No	20	
	70 x 40	P	No	Yes & 4	12	
9 v 9	52 x 58	GK	Big goals & 2	Yes & 2	14	
	55 x 53	GK	Big goals & 2	No	24	
	57 x 64	GK	Big goals & 2	No	20	
	59 x 53	GK	Big goals & 2	No	26	
	72 x 62	P	Small goals & 6	Yes & 2	34	
	84 x 50	GK	Big goals & 2	No	12	
10 v 10	38 x 32	P	No	Yes & 1	12	No offside rule was applied The balls were replaced from goals (if there was) Verbal encouragement or feedback was allowed from coaches throughout the task The neutral player (if there was) was always playing with the team in possession of the ball
	42 x 40	P	Small goals & 4	No	13	
	44 x 53	P	No	Yes & 2	26	
	50 x 40	P	No	Yes & 2	11	
	52 x 40	GK	Big goals & 2	No	64	
	54 x 53	GK	Small goals & 4	No	34	
	57 x 52	GK	Big goals & 2	No	34	
	67 x 62	GK	Big goals & 2	No	26	
	67 x 64	P	Small goals & 4	Yes & 1	30	
	68 x 50	P	Small goals & 4	No	9	
	68 x 53	P	Small goals & 6	No	36	
	68 x 53	P	Small goals & 4	No	15	
	72 x 62	P	Small goals & 4	No	30	
	72 x 64	P	No	No	16	
	72 x 64	P	Small goals & 6	No	24	
	75 x 53	GK	Big goals & 2	No	23	
	84 x 50	GK	Big goals & 2	No	42	
	84 x 53	GK	Big goals & 2	No	39	
	88 x 64	GK	Big goals & 2	No	15	
	100 x 50	GK	Big goals & 2	No	39	
	100 x 53	GK	Big goals & 2	No	98	
	104 x 62	GK	Big goals & 2	No	15	
	104 x 64	GK	Big goals & 2	No	24	

Table 3. Chronology and description of eccentric training methodology.

	Week															
Format	W1.1	W1.2	W1.3	W1.4	W2.1	W2.2	W2.3	W2.4	W2.5	W2.6	W2.7	W2.8	W3.1	W3.2	W3.3	
1 v 1	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	**10**
2 v 2	0	0	0	0	0	10	8	0	0	0	0	0	0	0	0	**18**
3 v 3	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	**30**
4 v 4	0	0	9	4	0	13	0	0	0	0	0	0	0	0	0	**26**
5 v 5	0	0	0	0	16	0	0	0	0	0	28	0	0	0	0	**44**
6 v 6	0	0	0	0	0	0	14	0	0	48	0	0	0	0	40	**102**
7 v 7	0	14	0	0	0	0	0	0	6	0	0	0	0	0	0	**20**
8 v 8	0	0	0	12	0	0	20	0	0	0	0	13	0	0	17	**62**
9 v 9	0	0	12	0	38	0	0	20	0	0	0	26	0	34	0	**130**
10 v 10	26	16	18	30	73	13	58	26	48	123	62	24	46	34	78	**675**
Total	**26**	**30**	**39**	**46**	**127**	**46**	**100**	**76**	**54**	**171**	**90**	**63**	**46**	**68**	**135**	**1117**

Statistical Analysis

All statistical analyses were performed using statistical software R, version 4.2.1 (R Core Team, 2020) for Macintosh. Data are presented as mean ± standard deviation (sd). The normality assumption was checked graphically and with the Shapiro-Wilk test. All analyzed variables showed a normal distribution. Prior to the intervention, a t-test for independent samples was performed to determine whether there were differences in the conditional profile between groups (Control and Intervention). Dependent measures derived from the external load were converted to zScore (Z) values. The formula is $Z = (x - M)/sd$, where x is the individual player score and M is individual player average for each SSGs analyzed and sd is the individual player standard deviation. Positive Z values indicate scores that are greater than the mean of the pooled sample, and negative values indicate scores that are less than the pooled mean. A 2-way (time [Pre-Intervention, Intervention vs. Post-Intervention] × group [CON vs. INT]) analysis of variance (ANOVA) was performed to examine the effects of the EOT on each performance variable. Pair-wise comparisons between time were conducted via Bonferroni post-hoc test. Effect size (ES) was established using Cohen's d. According to Cohen (2013), ES were classified as trivial (< 0.1), small (0.1 - 0.3), moderate (0.3 - 0.5), large (0.50 - 7) and very large (> 0.7). For all analyses, the statistical significance was set at $p < 0.05$.

Results

Table 4 presents the mean and standard deviation for each external load variable across the various SSGs analyzed. Figure 1 illustrates the differences between the intervention and control groups across the 15-week study, focusing on TDC, HSD, and SD. The TDC zScore was significantly higher in the intervention group compared to the control group during weeks W1.4 (ES = 0.8; $p < 0.05$) and W2.4 (ES = 0.7; $p < 0.05$). No significant differences were found between the groups during the other weeks. Similarly, the HSD zScore was significantly higher in the intervention group during weeks W1.4 (ES = 0.9; $p < 0.05$), W2.1 (ES = 0.5; $p < 0.05$) and W2.4 (ES = 0.5; $p < 0.05$). In terms of SD, no significant differences were observed between the groups, except for a notably higher SD zScore in the intervention group during W1.4.

Figure 2 shows the mechanical values. When considering ACC zScore, the control group demonstrated significantly higher values during weeks W2.2, W2.3, and W2.8 compared to the intervention group (ES = 0.4 - 0.7; $p < 0.05$). In contrast, DEC zScore was higher in the intervention group during weeks W2.1 and W2.4 (ES = 0.4 and ES=0.5, respectively; $p < 0.05$). No significant differences were observed between the two groups for ACC or DEC across the remaining weeks. Regarding PL, the control group recorded higher zScore during weeks W2.3, W2.6, W2.8, and W3.3 (ES = 0.4 - 0.7; $p < 0.05$), while the intervention group had significantly higher zScore during W2.4 (ES = 0.6; $p < 0.05$).

Figure 3 and Table 5 illustrate the differences between the two groups across the three measurement points (i.e., Pre-Intervention, Intervention, and Post-Intervention) for both locomotor and mechanical variables. Considering locomotor measures, no significant differences were found between the groups, including TD zScore, HSD zScore, and SD zScore, indicating that the eccentric-overload training did not have a noticeable impact on these aspects. However, significant differences emerged between the groups for the mechanical measures. Specifically, the intervention group exhibited significantly lower ACC and DEC zScores compared to the control group ($p < 0.001$), suggesting that eccentric training may reduce acceleration and deceleration demands. Additionally, the intervention group showed consistently lower PL zScores across all three measurement phases, with a significant interaction between group and time ($p < 0.01$), indicating a sustained effect of the training on physical load over time.

Table 4. Average and DT and Small sided games.

Format	$TD \cdot min^{-1}$	$HSD \cdot min^{-1}$	$VHSD \cdot min^{-1}$	$SD \cdot min^{-1}$	$ACC \cdot min^{-1}$	$DEC \cdot min^{-1}$	$PL \cdot min^{-1}$
1 v 1	78.6 ± 14.1	6.2 ± 5.6	1.9 ± 2.0	1.7 ± 1.9	1.1 ± 0.7	1.8 ± 1.4	32.4 ± 7.7
2 v 2	107.0 ± 13	2.6 ± 3.4	0.3 ± 1.3	0.3 ± 1.3	0.7 ± 0.6	0.8 ± 0.8	37.0 ± 4.3
3 v 3	102.0 ± 11.2	5.2 ± 4.5	0.9 ± 1.4	0.9 ± 1.4	1.1 ± 0.6	1.0 ± 0.7	38.1 ± 8.2
4 v 4	94.2 ± 14.4	2.6 ± 2.3	0.3 ± 0.5	0.3 ± 0.5	0.5 ± 0.4	0.6 ± 0.3	29.2 ± 6.6
5 v 5	112.0 ± 10.7	4.1 ± 3.0	0.8 ± 1.3	0.7 ± 1.1	0.7 ± 0.5	0.7 ± 0.4	33.8 ± 5.5
6 v 6	94.9 ± 12.2	3.5 ± 3.8	0.8 ± 1.7	0.8 ± 1.4	0.5 ± 0.4	0.6 ± 0.4	30.1 ± 5.7
7 v 7	86.6 ± 15.0	3.8 ± 3.8	0.8 ± 0.9	0.7 ± 0.8	0.4 ± 0.3	0.6 ± 0.3	25,1 ± 4.3
8 v 8	83.7 ± 14.2	2.1 ± 2.6	0.6 ± 1.1	0.7 ± 0.7	0.5 ± 0.4	0.5 ± 0.4	24.0 ± 5.7
9 v 9	104 ± 13.3	7.6 ± 4.2	3.1 ± 2.5	2.0 ± 1.5	0.4 ± 0.3	0.6 ± 0.3	27.7 ± 5.3
10 v 10	101.0 ± 14.2	7.3 ± 5.2	3.1 ± 3.0	2.0 ± 1.8	0.4 ± 0.3	0.5 ± 0.3	26.8 ± 5.5
Pooled data	99.5 ± 14.8	6.3 ± 5.0	2.4 ± 2.8	1.6 ± 1.8	0.5 ± 0.3	0.6 ± 0.4	27.8 ± 6.2

Table 5. zScore values according to time intervention for each external load measure analyzed.

	Pre-Intervention		Intervention		Post-Intervention		ANOVA p		
	CON	INT	CON	INT	CON	INT	Group	Time	Time*Group
TDC zScore	-0.16 ± 1.1	0.22 ± 0.6	-0.04 ± 1.0	0.03 ± 0.8	0.01 ± 0.8	0.04 ± 0.8	0.064	0.828	0.142
HSD zScore	-0.05 ± 0.8	0.21 ± 0.8	0.14 ± 0.9	0.16 ± 0.9	0.18 ± 0.8	0.05 ± 0.9	0.691	0.608	0.122
SD zScore	-0.04 ± 0.8	0.19 ± 1.0	0.11 ± 0.9	0.09 ± 0.9	0.13 ± 0.9	-0.05 ± 0.8	0.662	0.723	0.104
ACC zScore	-0.04 ± 0.8	-0.04 ± 0.7	0.10 ± 1.1	-0.09 ± 0.9	0.07 ± 1.0	-0.09 ± 0.9	<0.01	0.803	0.578
DEC zScore	-0.16 ± 0.7	0.13 ± 0.8	-0.08 ± 1.0	0.08 ± 1.0	0.08 ± 1.0	-0.05 ± 1.0	<0.05	0.805	0.070
PL zScore	-0.09 ± 0.9	0.13 ± 0.7	0.07 ± 0.9	-0.09 ± 0.9	0.18 ± 0.9	-0.20 ± 0.9	<0.01	0.954	<0.01

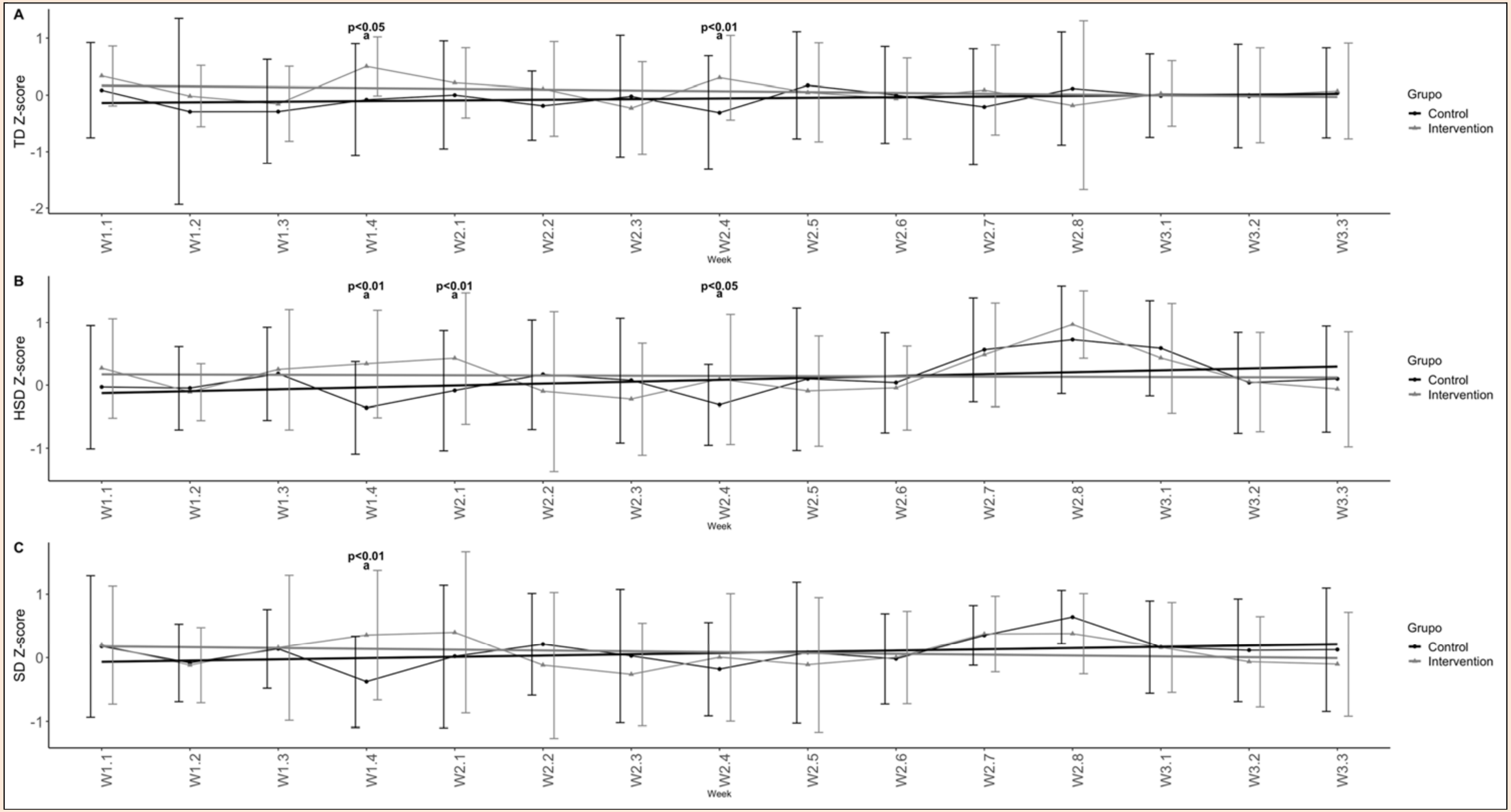

Figure 1. Differences between both groups over the 15-week study, focusing on locomotor values. A) TD zScore: zScore values of total distance covered; B) zScore values of high-speed distance (>18 km/h); C) zScore values of sprint distance (>21 km/h). [a] significant differences compared to control group ($p < 0.05$).

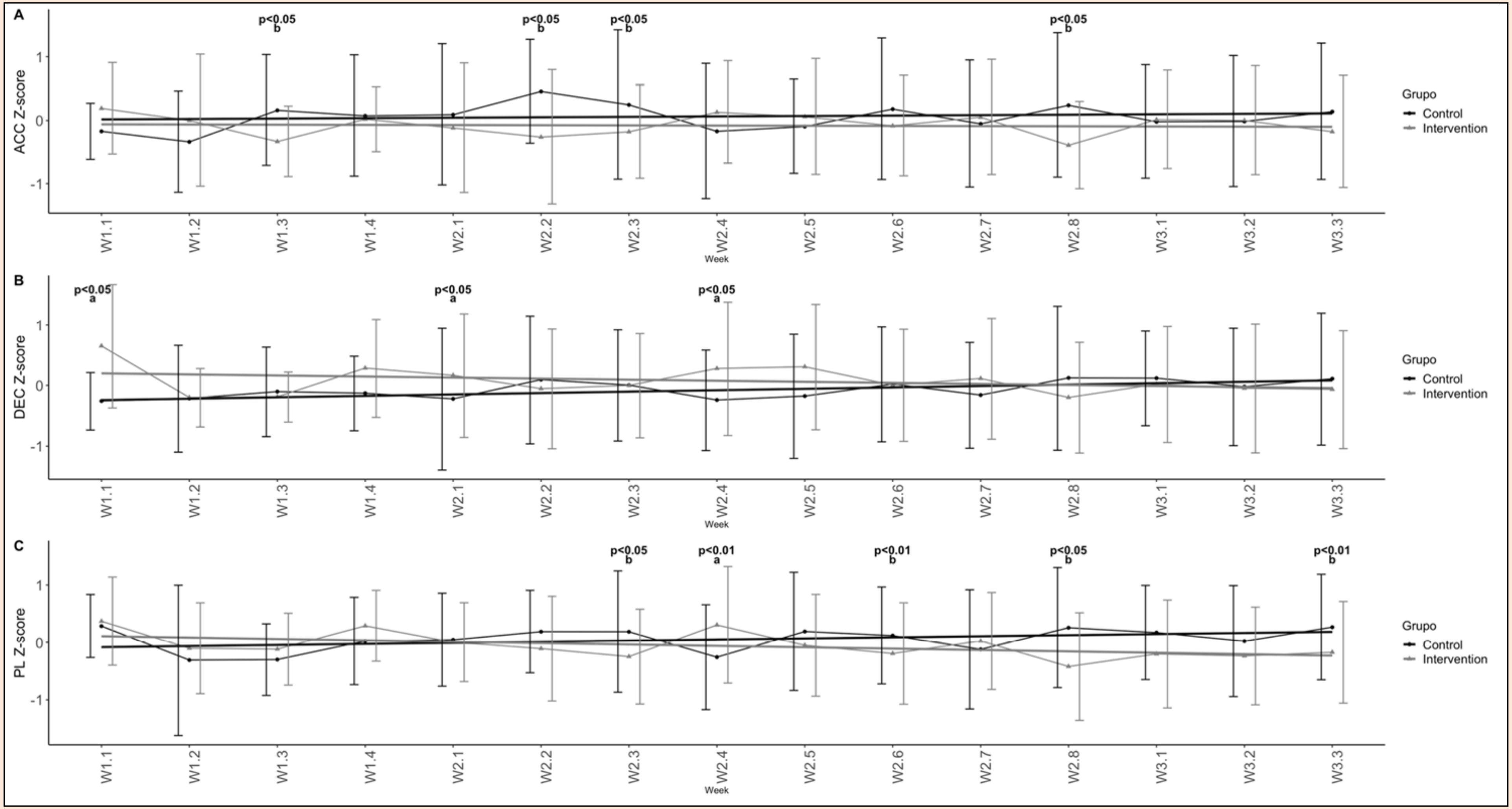

Figure 2. Differences between both groups over the 15-week study, focusing on mechanical values. A) ACC zScore: zScore values of high intensity accelerations ($< 3\ m\cdot s^2$); B) DEC zScore values of high-intensity decelerations ($<-3\ m\cdot s^{-2}$); C) PL zScore: zScore values of player load. [a] significant differences compared to control group ($p < 0.05$); [b] significant difference compared to intervention. group ($p < 0.05$).

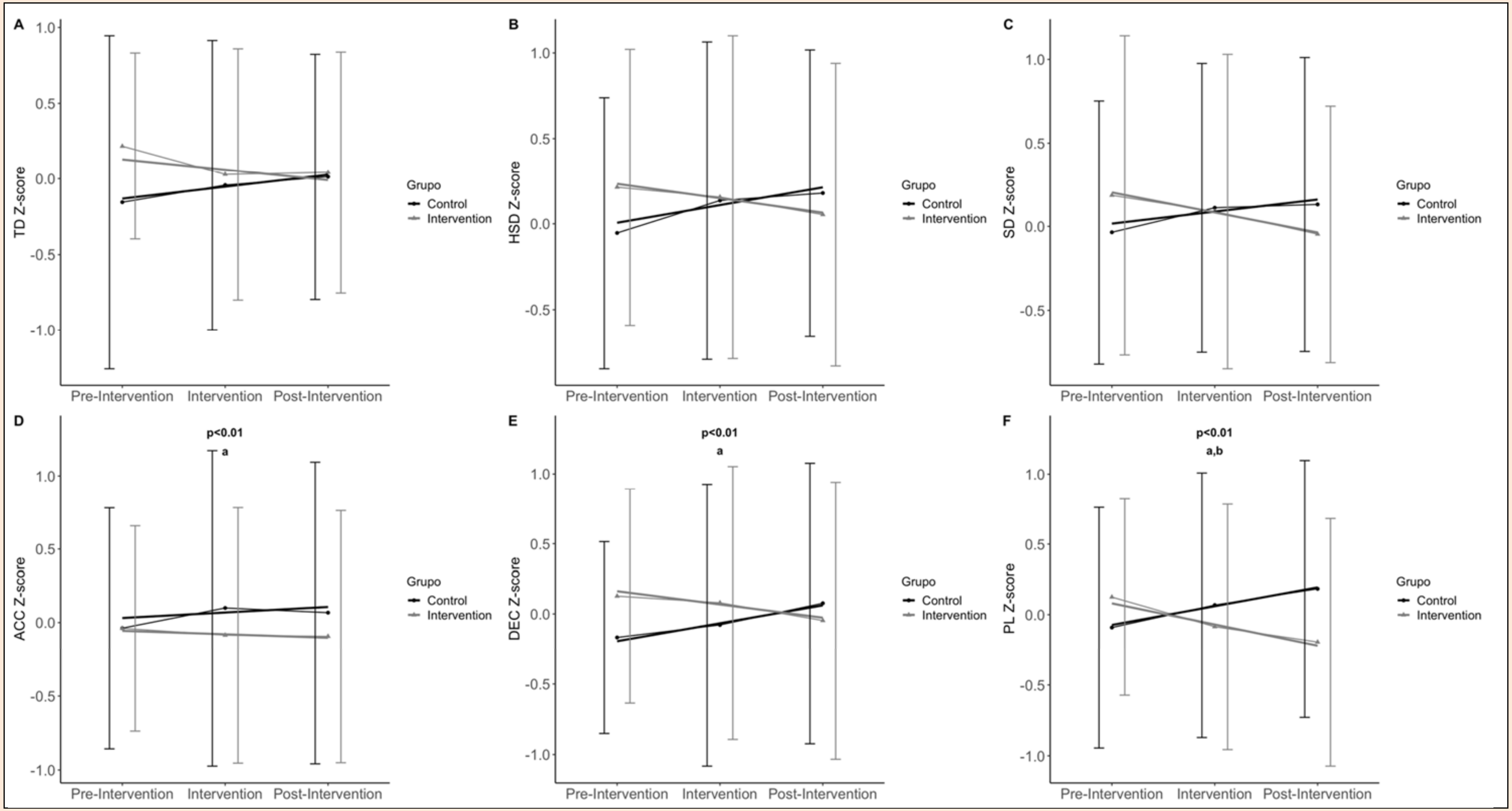

Figure 3. **Differences between the two groups across the three measurement points (i.e., Pre-Intervention, Intervention, and Post-Intervention). Note: A) TD zScore: zScore values of total distance covered; B) zScore values of high-speed distance (>18 km/h); C) zScore values of sprint distance (>21 km/h); D) ACC zScore: zScore values of high intensity accelerations (< 3 m·s^2); E) DEC zScore values of high-intensity decelerations (<-3 m·s-^{2}); F) PL zScore: zScore values of player load.** [a] significant difference between groups ($p < 0.05$); [b] significant differences between measurement points ($p < 0.05$).

Discussion

The aim of this research was to investigate the influence of integrating a weekly session of EOT on the locomotor and mechanical performance assessed through SSGs. The originality of the study lies mainly in the fact that the evaluation was not done by means of a laboratory test or a standardized test, but by analyzing the tasks that made up the training sessions carried out by the team before, during and after the eight weeks of intervention. The main findings of this study, indicate minimal week-to-week improvements in locomotor response and a slight decline in baseline mechanical response when comparing the intervention with control group. No significant differences were found between groups for the locomotor variables (i.e., TD zScore, HSD zScore, and SD zScore) across the three measurement points. However, significant differences were observed between the groups in the mechanical variables analyzed, including ACC, DEC, and PL.

Analyzing the weekly differences between the two groups, we found that during W1.4 and W2.4, the INT group exhibited significantly higher TD and HSD (in zScore) compared to the CON group. This outcome may be attributed to the specific task used during that week, as it did not represent a consistent trend across the other weeks. A possible explanation could be the increased training intensity due to more frequent high-intensity drills, with external factors potentially contributing to the elevated physical demands. No significant differences were observed between groups in the other analyzed weeks. These findings suggest that incorporating a weekly EOT session does not substantially impact locomotor performance during SSGs. In contrast, mechanical measures were affected for this type of training. According to Hody et al. (2019), EOT pose several risks, including delayed-onset muscle soreness and impaired muscle function. Furthermore, Doguet et al. (2019) suggest that eccentric contractions induce significant mechanical strain and alter corticospinal excitability, both of which are associated with reduced force production. These factors may help explain the observed reductions in mechanical performance in the intervention group. Hence, ACC zScore and PL zScore were reduced in the INT group during W2.2, W2.3, and W2.8 for ACC, and during W2.3, W2.6, and W3.3 for PL. Triaxial accelerometers (highly responsive motion sensors) record body movement acceleration across three dimensions. Movements involving accelerations and changes of direction are more energetically demanding than constant-velocity running. Even at low running speeds, high metabolic demands are placed on soccer players when acceleration levels are elevated (Dalen et al. 2016; de Hoyo et al. 2017). These metrics may be more sensitive to EOT-induced fatigue, as eccentric training can impair neuromuscular function, reducing force production and the ability to control rapid changes in speed and direction. Muscle damage from EOT, especially in the lower limbs, may affect the stretch-shortening cycle, crucial for ACC and DEC during SSGs. Additionally, Dalen et al. (2019) suggest that accelerations better predict performance declines in SSGs than high-speed or sprint distances, reflecting the cumulative neuromuscular fatigue linked to EOT. These facts could be behind the differences between locomotor and mechanical values during SSGs. As noted by Neme et al. (2013), eccentric (ECC) training may be superior for both strength and hypertrophy development compared to conventional concentric protocols. However, EOT tends to induce greater muscle damage, characterized by muscle swelling, delayed-onset muscle soreness, and elevated serum creatine kinase levels (Kanzaki et al. 2022). This suggests that EOT may require longer recovery periods than concentric and isometric contractions (Kanzaki et al. 2010), potentially influencing performance. The cumulative effect of repeated eccentric loading without adequate recovery could have exacerbated neuromuscular fatigue, limiting the players' ability to perform high-intensity actions during SSGs. Additionally, as above mentioned in SSGs, accelerations, decelerations, and COD are crucial movements, as high-intensity running and sprinting distances are less frequent, especially when using smaller playing areas and fewer players (de Dios-Álvarez et al. 2024). Regarding DEC zScore values, there appears to be a noticeable reduction throughout the study, particularly in the latter weeks of the intervention and the post-intervention weeks, especially in the INT group. Consistent with previous research (Nevado et al. 2021), EOT did not prevent the typical decline in ACC, DEC, and PL during SSGs. As mentioned earlier, fatigue may likely be a key factor underlying these findings.

When the weeks were grouped into three phases (Pre-Intervention, Intervention, and Post-Intervention), no significant differences were observed between groups across the study for the three locomotor measures analyzed. It is possible that the volume and intensity of the EOT implemented were insufficient to induce measurable changes in locomotor variables during small-sided games. Interestingly, previous studies (Núñez et al., 2018; Cook et al., 2013) reporting significant improvements in locomotor performance used lower training volumes or shorter intervention periods. However, contrasting evidence shows that flywheel training does not enhance sprint speed and acceleration in soccer players (Allen et al., 2023). Notably, these studies assessed performance through closed, controlled tests, while our study evaluated locomotor performance in the dynamic and variable context of small-sided games, potentially reducing sensitivity to detect changes. However, significant differences emerged between groups for ACC, DEC and PL zScore values. According to Norrbrand et al. (2011), flywheel resistance exercise employing eccentric overload, induce early and robust increase in strength and muscle mass that are greater than those reported with conventional resistance training exercises, due to its unique loading features. However, while proven effective in inducing robust muscle adaptations eccentric muscle activity could transiently reduce maximal strength and generating muscle damage (Fernández-Gonzalo et al., 2014), increasing protein degradation and disruption in the sarcomere architecture (Kanzaki et al. 2010), which may explain the observed reductions in ACC and DEC in the intervention group, likely as a result of fatigue and impaired neuromuscular performance associated with the eccentric overload training. Prolonged muscle damage from eccentric overload training (EOT) may reduce training efficiency by extending recovery time and impairing performance during subsequent sessions. High-intensity, unaccustomed eccentric exercises without sufficient recovery can lead to overtraining (Coutts et al., 2007), characterized by decreased muscle function and elevated markers of muscle damage, such as creatine kinase and lactate dehydrogenase (Malm et al., 2000). These findings suggest that accumulated fatigue from EOT, in the absence of tailored recovery protocols, may have contributed to the reduced mechanical performance observed during SSGs.

Consequently, implementing specific strategies to mitigate ECC-induced muscle damage and promote recovery is crucial for maintaining athletic performance during SSGs. These strategies may include adjusting EOT parameters, such as reducing training volume or intensity, incorporating longer recovery periods between sessions, and using recovery modalities like active recovery, cold-water immersion or compression garments (Calleja-González et al., 2021). Such interventions can help minimize muscle damage, reduce proteolytic activity, and facilitate faster muscle repair and adaptation (Fernández-Gonzalo et al., 2014). This could explain the muscle weakness and reduced performance experienced during SSGs without adequate recovery process in the INT group (Kanzaki et al. 2010). In line with Fitts (2008), the determinants of force output are the number of strongly bound cross- bridges and the force generated by them. Hence, knowing that the ATPase plays a central role in the cross-bridge cycle could explain the reductions of ACC, DEC and PL in the INT group, given that these measures are especially affected by metabolites, such as ADP, inorganic phosphate and H^+ which accumulate during anaerobic muscle contraction. Accordingly, practitioners should manage and adjust the EOT to prevent excessive fatigue and enhance performance. By tailoring the intensity and volume of EOT to individual needs, practitioners can optimize recovery and ensure sustained performance improvements, while also reducing the likelihood of overtraining or injury using this type of training. While eccentric loading offers rehabilitation and performance benefits, practitioners must carefully manage its integration by adjusting training volume, monitoring individual responses, and ensuring adequate recovery to minimize the risk of overuse injuries (Hickey et al., 2022).

This study has certain limitations that must be acknowledged. First, the small sample size could be considered a limitation, and therefore, the conclusions drawn from the findings should be interpreted with caution. Additionally, data from only one team were analyzed, limiting the generalizability of the results. A larger sample of teams and players would provide more representative and widely applicable findings. Second, variations in the duration and structure of the SSG formats may have influenced players' pacing strategies, which should be taken into account when analyzing the results. For instance, shorter SSGs on smaller pitches may have promoted higher-intensity efforts, while longer SSGs on larger areas encouraged conservative pacing to manage fatigue, affecting accelerations, decelerations, and high-speed running. Finally, incorporating a more precise quantification of EOT, such as eccentric peak force and total workload, would offer a deeper insight into the workload performed during these exercises. In addition, we acknowledge that the lack of randomization introduces potential bias and may limit the generalizability of our findings. Therefore, future studies should include a larger sample size, encompassing players of different ages and skill levels, and using controlled randomized study designs to better understand the influence of a weekly EOT session on athletic performance assessed through small-sided games SSGs. Additionally, adjusting the frequency of eccentric training sessions throughout the weeks, either increasing or decreasing, could be of interest to practitioners for optimizing performance outcomes. It would be beneficial conducting studies with larger and more diverse samples, including players from different age groups, competitive levels, and training backgrounds to improve the external validity of the findings.

Conclusion

The results show marginal increases in TD and HSD during specific weeks; however, these improvements were inconsistent throughout the intervention period, accompanied by a slight decline in baseline mechanical response when comparing the intervention and control groups. While no significant group differences were found in locomotor variables such as TD, HSD, and SD zScore across the three measurement points, significant differences were observed in mechanical variables, including ACC, DEC, and PL. This indicates that while locomotor demands were largely unaffected by EOT, mechanical performance was more sensitive to the intervention. Weekly EOT sessions can be cautiously integrated into training, but practitioners must account for potential declines in mechanical performance, particularly in accelerations and decelerations, provided players have adapted to the new stimulus. However, accumulated fatigue from EOT may impact mechanical performance in SSGs, especially over the medium to long term.

Practical applications

From a practical standpoint, this study suggests that preventive exercises like EOT could be incorporated into regular training routines without diminishing performance, supporting injury prevention without compromising physical or technical output in training and competition. Preventive exercises like EOT may enhance muscle strength and coordination, contributing to injury prevention while maintaining players' overall workload during SSGs. Practitioners should progressively adjust EOT intensity, monitor individual recovery rates using tools like wellness questionnaires or biomarkers, and schedule EOT sessions around match and training demands to prevent excessive fatigue.

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Key points

- Eccentric overload training did not affect locomotor performance during small-sided games.
- Eccentric overload training showed some reduction in acceleration, deceleration, and mechanical loading during small-sided games.
- Eccentric overload training can be cautiously integrated into training, provided players have adapted to the new stimulus.
- Assessment in a real-world setting improves ecological validity but limits experimental control.

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