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Effect of a Short-Term Combined Balance and Multidirectional Plyometric Training on Postural Balance and Explosive Performance in U-13 Male and Female Soccer Athletes

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Abstract: This study's aim is to examine the effect of a combined balance and multidirectional plyometric training intervention on postural balance ability and lower limb explosive performance in U-13 male and female soccer athletes. Twenty pre-adolescent (age: 12.6 ± 1.6 years) soccer athletes followed a 6-week training intervention combining balance exercises, dynamic stabilization tasks and multidirectional plyometric exercises at a frequency of twice/week for 20–25 min, based on a progressive increase in exercise difficulty from phase A (week 1–3) to phase B (week 4–6). Pre- and post-training measurements were carried out to assess the following: (a) static balance performance in single (left, right)-legged and two-legged quiet stance trials with eyes open and eyes closed (two trials per stance and vision condition of 30 s duration) and (b) lower limb explosive performance in countermovement and squat jumps without arm swing (three trials/jump). The vertical GRF was recorded by a customized force plate (Wii, 1.000 Hz, Biovision) and offline, CoP and explosive performance parameters were calculated. The overall results showed that the static balance ability of athletes remained unaffected, while restricting their vision deteriorated their postural control. The lower limb explosive performance showed a trend for improvement; however, inter-individual variations in athletes' responses might have obscured any effect.

Keywords: static balance; plyometrics; biomechanical analysis; jumping performance; preadolescence; soccer

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1. Introduction

Soccer is listed as the top activity in the preferences of children and adolescents with regards to their participation in sport- and leisure-time physical activities [1]. Muscle strength and power constitute critical parameters that relate to performance in soccer [2], since due to the sport's intermittent nature, along with the high physical and energetic demands [3], substantial parts of the total covered distance are performed at high or very high intensity [4]. Moreover, within the context of the athletes' technical and tactical choices, a major part of their actions is based on rapid and sudden change-of-direction movements [5]. To enhance and optimize muscle strength and power in athletes, soccer training applies plyometric training [6]. As is well known, plyometric training is based on the concept of training specificity by advocating the use of vertical and horizontal jumps and displacements in order to improve performance by the transference of gains in strength and power to performance parameters related to vertical and horizontal force production (for example, vertical–horizontal jumps, sprints) [7]. A recent meta-analysis that compared the effect between vertically and horizontally orientated plyometric training on physical performance showed that both methods were effective at enhancing respective outcome measures [8]. It was also shown that horizontally orientated plyometric training might be a more efficient method for enhancing multi-vector performance-related measures. Soccer's movement patterns are predominantly multidirectional, and, indeed, previous studies have found greater benefits of multidirectional plyometric training [9–12] compared to single-vector (vertically or horizontally directed) plyometric training on soccer performance. Despite the relative homogeneity of those studies in training frequency and intervention duration [9–12], there is, however, a paucity of studies focusing on investigating female athletes and especially of preadolescent age, since most of the existing evidence is derived from young or adult male athletes.

Balance, on the other hand, is a fundamental skill that contributes both to the efficient technical execution of a sport's movements and to injury prevention, while an improvement in postural control will enhance athletic performance [13]. In soccer, the complexity of technical actions, for which unilateral stance and/or body weight transfer is frequently required in combination with unpredictable situations during training or the game, which demand postural regulation of the body (e.g., unpredicted changes of ball direction, interference with the opponent while being in motion, strenuous physical contact in an offensive or defensive action, etc.), constitute the necessary development of postural skills in soccer players [14,15]. Previous short-term training balance interventions in young and adult soccer athletes have shown improvements in static and dynamic balance as well as in technical features [16–18]. Moreover, the implementation of a balance training program throughout the competitive season (~40 weeks) resulted in a significant enhancement in dynamic balance performance and a respective decrease in the percentage occurrence of lower extremity injuries in young soccer players [19]. Further, the effect of balance training and plyometric training interventions has been investigated in young soccer athletes, either separately [20,21] or with a variation in training sequence [22] or with alternating training schedules within the total intervention duration [23]. Findings have not been conclusive up to now with regards to the stronger influence of one training intervention or training sequence over another, as some researchers have found greater adaptations in performance measures related to balance, jumping ability and velocity, when 4 weeks of plyometric training were preceded by balance training of equivalent duration [22].

Vision is the main structure involved in postural control as it provides input, enabling the body to actively control its alignment for the purposes of orientation and stability [24]. The contribution of visual information has been studied in athletic activities, where regulation of the body's posture and/or perception of its orientation with regards to the external environment by means of sensory input is critical for successful performance [25,26]. Expert soccer players were found to have smaller dependence on vision for postural control compared to less experienced players, and they used vision for processing game-related information, like cooperation with other team members or interaction with the opponents [15].

Therefore, in the present study, we were interested in the implementation of a combined balance and plyometric training intervention in male and female preadolescent soccer athletes, aiming at the collection of evidence to be used by coaches and strength and conditioning trainers to design training programs for performance optimization. The study's primary purpose was to examine the possible effect of short-term balance and multidirectional plyometric training on balance and lower limb explosive performance in male and female preadolescent soccer athletes. It was hypothesized that the short-term combined balance and multidirectional plyometric training would improve the balance and the lower limb explosive ability in the athletes. A secondary purpose was to examine possible differences between male and female soccer athletes resulting from the possible effect of the combined training intervention. The study's final purpose was to investigate the interaction between the training intervention and a restriction of vision. Considering previous findings on the visual contribution in athletic activities, we hypothesized that the short-term combined balance and multidirectional plyometric training would assist the athletes in relying on the other sources of available sensory information, when vision was restricted, to regulate their postural control.

2. Materials and Methods

2.1. Participants

Twenty (ten male and ten female) pre-adolescent (aged 12.6 ± 1.6 years) soccer athletes with a training experience of 4.5 ± 2.7 years volunteered to participate in this study. Inclusion criteria required that the athletes had participated in a minimum of 80% of the team's training during the last 3 months prior to the start of the study and did not report any ligamentous or musculoskeletal injury in the last 6 months. The athletes trained systematically at a frequency of 3–4 sessions per week for 90 min and competed in one weekly game at the regional championship of the Greek Association of Soccer Clubs in the U-13 category. All athletes and their parents or legal guardians gave their written informed consent to participate in this study in accordance with the Helsinki Declaration after being thoroughly informed about the study's procedures. The study was approved by the Ethics Committee of the School of Physical Education and Sport Science, National and Kapodistrian University of Athens (approval number: 1520/2023).

2.2. Study Design and Intervention Protocol

A one-group repeated-measures design was applied with pre-training (PRE) and post-training (POST) measurements. Soccer's demanding nature with regards to physical and neuromuscular requirements necessitates multimodal training approaches. To that aim, based on previous work that implemented solely plyometric [9–12] or balance training [16,18,21] or a combination of both [22,23,27], we designed a 6-week training intervention (2 sessions/week, 20–25 min/session), comprising static balance tasks, dynamic stabilization tasks and multidirectional plyometric exercises. The intervention was divided into two phases of 3 weeks duration each, which were characterized by a progressive increase in task/exercise difficulty with regards to the base of support (two-legged vs. single-legged base of support), visual information (eyes open vs. eyes closed), movement direction and execution velocity [28,29]. Table 1 presents, in detail, the implemented training intervention. Prior to the main part of their afternoon typical soccer training, the athletes followed a standardized warm-up of 5–7 min in duration, involving jogging and 2–3 running drills at light intensity followed by dynamic stretching of the major muscle groups of the upper and lower body, and then carried on with the training intervention. Caution was taken so that a 48 h break period apart from training sessions occurred to avoid fatigue and to provide full recovery. Athletes participated in two familiarization sessions before the start of the training intervention. In one of those sessions, anthropometric measurements of body mass, height, sitting height and left and right lower limb length (measured distance from the top iliac crest to medial malleolus in the supine position) were carried out. Biological maturation was assessed based on the equations, as previously proposed [30].

Table 1. Combined balance and multidirectional plyometric training intervention of the study.

Phase ^{A}	**Balance Tasks**	**Set × Exercise Duration/Rest**	**Dynamic Stabilization Tasks**	**Set × Exercise Duration/Rest**	**Multidirectional Plyometric Exercises**	**Set × Exercise Duration/Rest**
	Two-legged stance-EC *	1 × 30 s/ 15 s	Forward Walking Lunge - Execution rate: Slow Distance: short	1 × 15 s per leg/ 15 s	Standing vertical jump with alternating unipedal landing	1 × 30 s/ 15 s
	Single-legged stance-EO *	1 × 30 s/ 15 s	Diagonal Forward Lunge – Execution rate: slow Distance: short	1 × 15 s per leg/ 15 s	Side jumps	1 × 30 s/ 15 s

Table 1. *Cont.*

Phase [A]	Balance Tasks	Set × Exercise Duration/Rest	Dynamic Stabilization Tasks	Set × Exercise Duration/Rest	Multidirectional Plyometric Exercises	Set × Exercise Duration/Rest
A′ **Weeks: 1–2–3** **Warm up [B]: ~5′–7′**	Two-legged stance on bosu ball-EO	1 × 30 s/ 15 s	Ski Jumps - Distance: short	1 × 30 s/ 15 s	Lateral Step-Up jumps	1 × 30 s/ 15 s
	Single-legged stance on Balance Disk-EO	1 × 30 s per leg/ 15 s	Single Leg Ski Jumps - Distance: short	1 × 15 s per leg/ 15 s	Drop jumps from a bosu ball to the ground	1 × 30 s/ 15 s
	Single-legged stance with hip rotation-EO	1 × 15 s per leg / 15 s	-	-	Vertical jump from a bosu ball to a box of 20 cm height	1 × 30 s/ 15 s
	Plank with alternating shoulder rotation	1 × 30 s per side/ 15 s	-	-	Static jumping lunges - Execution rate: slow	1 × 30 s/ 15 s
	-	-	-	-	Single-legged Rise Dead Lifts	1 × 15 s per leg/ 15 s
B′ **Weeks: 4–5–6** **Warm up [B]: ~5′–7′**	Single-legged stance-EO	1 × 30 s/ 15 s	Forward walking lunge and core rotation with a ball – Execution rate: fast Distance: long	1 × 15 s per leg/ 15 s	Horizontal Jump, Hand on the hips and landing on the toes - Distance: Long	1 × 60 s/ 60 s
	Single-legged stance-EC	1 × 30 s/ 15 s	Diagonal forward lunge - Execution rate: fast Distance: long	1 × 15 s per leg/ 15 s	Repeated horizontal jumps with hands on the hips and landing on the toes - Distance: long	1 × 75 s/ 60 s
	Single-legged stance on Balance Disk-EO	1 × 30 s per leg / 15 s	Ski Jumps - Distance: long	1 × 30 s/ 15 s	-	-
	Single-legged stance on ground with hip rotation-EO	1 × 15 s per leg/ 15 s	Single Leg Ski Jumps - Distance: long	1 × 15 s per leg/ 15 s	-	-
	Plank with alternating shoulder rotation	1 × 15 s per side/ 15 s	-	-	-	-

[A] Frequency of training in phase A and B was two sessions/week, 20–25 min duration. [B] Warm-up consisted of jogging and 2–3 running drills at light intensity followed by dynamic stretching of the major muscle groups of the upper and lower body. * EC–EO: eyes closed, eyes open.

2.3. Static Balance Assessment

From a biomechanical perspective, the two-legged quiet stance is treated as the most conventional condition of balance assessment in order to gather evidence about a subject's ability to regulate one's center-of-mass oscillations within the limits of the base of support [31,32]. This test is typically accompanied by single-legged stance trials, for they are considered the basic mode of postural challenge with regards to manipulating the base of support [31]. This method of static balance assessment has been previously used either in children or adolescents [29,33,34] as well as in athletes [35,36]. Therefore, the assessment of static balance took place before (PRE) and after the 6-week period (POST) of the training intervention during single-legged and two-legged quiet stance trials in a quiet and spacious room of the sport club's facilities. During assessment of the single-legged stance trials, the athletes were instructed to assume a straight body posture with their arms hanging relaxed by their sides, to flex their hip joint and their knee joint at 90 degrees and to stand as motionless as possible on the force plate with either left or right leg. For the two-legged trials, the athletes assumed the same posture as described above, with their feet hip width apart. During the trials with eyes open, the athletes were instructed to fix their gaze on an imaginary point on the wall 2–3 m in front of them, while keeping their heads in a neutral position parallel to ground level, while during the trials with eyes closed, care was taken so that one researcher was always situated behind the athletes for safety reasons. Two successful trials per stance and visual condition were performed in a randomized order of 30 s duration each with 15 s of rest across trials and 1 min between testing conditions. Static balance performance was determined by the recording of center-of-pressure (CoP) data with a vertical force plate (Wii, A/D converter, 24-bit resolution, 1.000 Hz, Biovision, Wehrheim, Germany). Offline, the data were filtered using a 2nd bi-directional-order digital low-pass Butterworth filter with a 15 Hz cut-off frequency and analyzed with MATLAB custom-made scripts (R2012a, 64 Bit; Mathworks, Natick, MA, USA) from the 5th to the 25th second ($\Delta t = 20$ s) of each 30 s trial duration. Based on the CoP displacement, whose derived values represent the geometrical location of the vertical ground reaction force vector on the platform during quiet standing [37], the following parameters were determined: (a) CoP path length, defined as the sum of Euclidean distances between adjacent measurement points, and (b) CoP sway range, defined as the range (i.e., from minimum to maximum) of the CoP values in the anteroposterior and mediolateral directions. To assess performance in the two-legged quiet stance trials, the average values of the two trials were used, whereas in the single-legged trials, the average value of the mean left and right leg trials was used for analysis, since no statistically significant differences were observed between sides (paired t test: $p > 0.05$) in any parameter.

2.4. Explosive Performance Assessment

The assessment of lower limb explosive performance before (PRE) and after the 6-week training period (POST) was based on a protocol of countermovement (CMJ) and squat jumps (SJ) [38,39] by recording the ground reaction force with the use of a vertical force plate, as described above. Following a short familiarization period, during which the athletes performed 2–3 submaximal CMJs and SJs, where they were instructed to focus on (a) starting the propulsion phase from a position of 90-degrees knee flexion along with no countermovement for the SJ and from an erect position for the CMJ, (b) having a depth of the downwards movement that would allow for an unobstructed propulsion phase and (c) reaching full lower limb extension at the apex of the jump, they performed three successful CMJs and three SJs for maximum height without arm swing. A rest interval of 2 min between familiarization and measurements and 30 s between jump trials was provided to minimize fatigue. The trial with the highest height achieved was selected for further analysis, and explosive performance was determined by the parameters of jump height (m), maximum force (N), maximum impulse (N·s), and mean and maximum mechanical power (Watt) for the CMJ and SJ.

2.5. Statistical Analysis

For the statistical analysis, we first checked for the normal distribution of the CoP data using the Kolmogorov–Smirnov test with Lilliefors correction. Two-way ANOVAs for repeated measures were performed with training intervention (PRE vs. POST measures) as the within-subjects factor, and (a) sex (male vs. female) and (b) vision restriction (eyes open vs. eyes closed) as the between-subjects factors to check for possible differences in the dependent variables of CoP path length, CoP anteroposterior and CoP mediolateral sway during the single-legged and two-legged static balance assessments. In the event of a significant main or interaction effect, a Bonferroni-corrected pairwise analysis was conducted. Similarly, two-way ANOVA for repeated measures with training intervention and sex as fixed factors was performed to test for possible differences in the anthropometric and lower limb explosive performance outcome measures with post hoc Bonferroni-corrected pairwise analysis. The percentage change due to training intervention was calculated (($\%\Delta$: (POST $-$ PRE)/POST $\times$ 100%), and Cohen's d with values of $0.2 < d \leq 0.5$, $0.5 \leq d < 0.8$ and $d \geq 0.8$ determining a small, medium or large effect size due to training intervention was calculated [40]. All statistical analyses were performed using SPSS IBM v.21, and the significance level was set at a = 0.05.

3. Results

3.1. Anthropometric Characteristics

Due to the non-statistically significant training intervention by the sex interaction effect in any anthropometric parameter, Table 2 presents the anthropometric characteristics of all the athletes and the effect size of training intervention, based on the results of paired-sample *t* test analysis. After the 6-week training period, age (t (19) = 71.1), body mass (t (19) = 4.1), body height (t (19) = 4.7) and lower limb length (t (19) = 3.6) were significantly increased. There was no statistically significant difference in maturity offset (t (19) = 1.9, $p = 0.605$) and body mass index (t (19) = 1.7, $p = 0.098$) (Table 2).

Table 2. Male and female soccer athletes' anthropometric characteristics before (PRE) and after (POST) the combined balance and multidirectional plyometric training intervention.

Parameter	PRE	POST	%Δ	Cohen's d
Age (years)	12.6 ± 1.6	12.7 ± 1.6 ***	+0.8%	0.10
Maturity offset (years) ^{a}	−0.76 ± 1.46	−0.75 ± 1.49 ^{ns}	+1.8%	0.01
Body mass (kg)	47.1 ± 10.8	48.2 ± 11.1 ***	+2.3%	0.09
Body height (cm)	157.1 ± 13.4	158.0 ± 13.1 ***	+0.6%	0.07
Body mass index (kg/m^2)	18.8 ± 1.9	19.0 ± 2.1 ^{ns}	+1.1%	0.10
^{b} Lower limb length (cm)	83.5 ± 6.8	84.3 ± 7.2 **	+1.0%	0.10

^{a} Years to the age at peak height velocity. ^{b} Average value of the left and right lower limb length. %Δ: Post- vs. pre-measurements. Statistically significant difference between pre–post measurements: *** $p < 0.001$, ** $p < 0.01$, ^{ns} $p > 0.05$. Data are mean ± SD.

3.2. Static Two-Legged Balance Performance

With regard to results on two-legged static balance performance, due to the non-statistically significant training intervention by the sex interaction effect in any CoP parameter, the results refer to the main effect of training intervention and vision and to the training intervention considering the vision interaction effect. Specifically, there was a significant main effect of training intervention only in the anteroposterior CoP sway range ($F_{1,38} = 7.52$, $p = 0.009$), with higher values post-training (PRE vs POST measurement: 1.8 ± 0.4 vs. 2.5 ± 0.3 cm) (Figure 1B). There were no significant differences due to training intervention for the CoP path length ($F_{1,38} = 0.35$, $p = 0.564$, Figure 1A) and the sway range in the mediolateral direction ($F_{1,38} = 2.38$, $p = 0.131$, Figure 1C). Vision had a significant main effect in the CoP path length ($F_{1,38} = 30.12$, $p < 0.001$), with a higher CoP displacement found for the eyes-closed condition (Figure 1A). No statistically significant differences were found for either the anteroposterior ($F_{1,38} = 0.14$, $p = 0.706$, Figure 1B) or the mediolateral CoP sway range ($F_{1,38} = 0.54$, $p = 0.468$, Figure 1C) due to vision restriction. The interaction effect of training intervention and vision was statistically significant ($F_{1,38} = 29.67$, $p < 0.001$) in the CoP anteroposterior sway range, where athletes had significantly higher CoP sway values after the 6-week training intervention with eyes closed, as compared with the lower increase in the respective values in the eyes-open condition (Figure 1B). There was a non-statistically significant training intervention for the vision interaction effect for the CoP path length ($F_{1,38} = 0.46$, $p = 0.500$, Figure 1A) and the sway range in the mediolateral direction ($F_{1,38} = 0.20$, $p = 0.661$, Figure 1C).

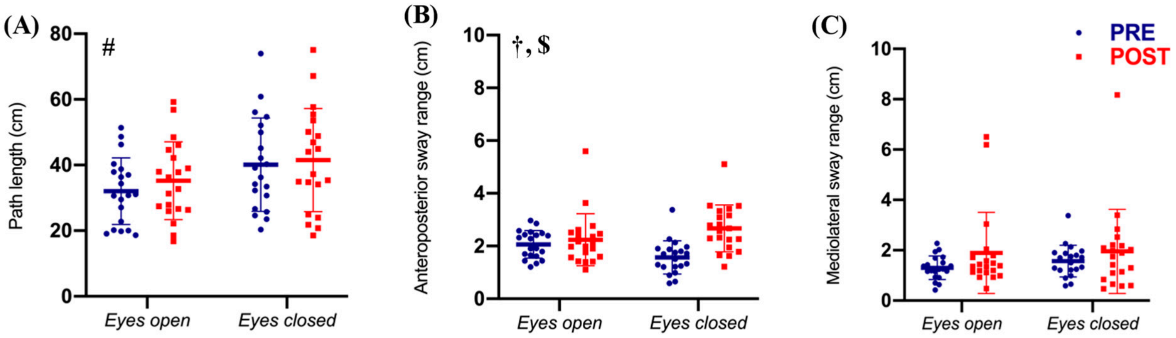


Figure 1. Static two-legged balance performance as determined by: (**A**) CoP path length, (**B**) CoP anteroposterior sway range, and (**C**) CoP mediolateral sway range with eyes open and eyes closed before (PRE, blue circles) and after the 6-week (POST, red squares) training intervention. # Statistically significant main effect of vision, $p < 0.001$. † Statistically significant main effect of training intervention, $p < 0.01$. $ Statistically significant interaction effect of training intervention and vision, $p < 0.001$. Data in scatterplots are individual values and the mean ± SD value is also depicted.

3.3. Static Single-Legged Balance Performance

In Table 3, the results on static single-legged balance performance are shown. The analysis did not yield any statistically significant training intervention by the sex interaction effect in any CoP parameter in the single-legged balance assessment; thus, the results presented here refer to the main effects of training intervention and vision, and to the training intervention by the vision interaction effect. Training intervention did not have a significant main effect on the CoP path length ($F_{1,38} = 0.002$, $p = 0.969$), range of CoP sway in the anteroposterior ($F_{1,38} = 0.11$, $p = 0.745$) and the mediolateral direction ($F_{1,38} = 0.03$, $p = 0.867$)). A significant main effect of vision was found for the CoP path length ($F_{1,38} = 180.2$, $p < 0.001$), the anteroposterior ($F_{1,38} = 133.8$, $p < 0.001$) and mediolateral sway range ($F_{1,38} = 66.8$, $p < 0.001$). There was a non-statistically significant training intervention by vision interaction effect in the CoP path length ($F_{1,38} = 0.07$, $p = 0.800$), the anteroposterior ($F_{1,38} = 1.1$, $p = 0.299$) and the mediolateral CoP sway range ($F_{1,38} = 0.18$, $p = 0.677$) (Table 3).

Table 3. CoP parameters in the single-legged quiet stance trials with eyes open and eyes closed before (PRE) and after (POST) the combined balance and multidirectional plyometric training intervention.

CoP Parameter	Vision	PRE	POST	%Δ	Cohen's d
Path length (cm)	Eyes open	127.9 ± 25.2	129.9 ± 25.0	+1.6%	0.08
Anteroposterior sway range (cm)		5.8 ± 2.1	4.9 ± 1.7	−15.2%	0.46
Mediolateral sway range (cm)		4.2 ± 1.3	3.8 ± 1.4	−9.5%	0.30
Path length (cm)	Eyes closed	258.4 ± 65.5	255.5 ± 66.1	−1.1%	0.04
Anteroposterior sway range (cm)		11.9 ± 3.9	12.2 ± 4.3	+2.8%	0.08
Mediolateral sway range (cm)		9.2 ± 4.5	9.4 ± 4.0	+1.6%	0.03

Note: Results are the average value of the left and right lower limb due to no statistically ($p > 0.05$) significant difference in the examined parameters. %Δ: Post- vs. pre-measurements. Data are mean ± SD.

3.4. Explosive Performance

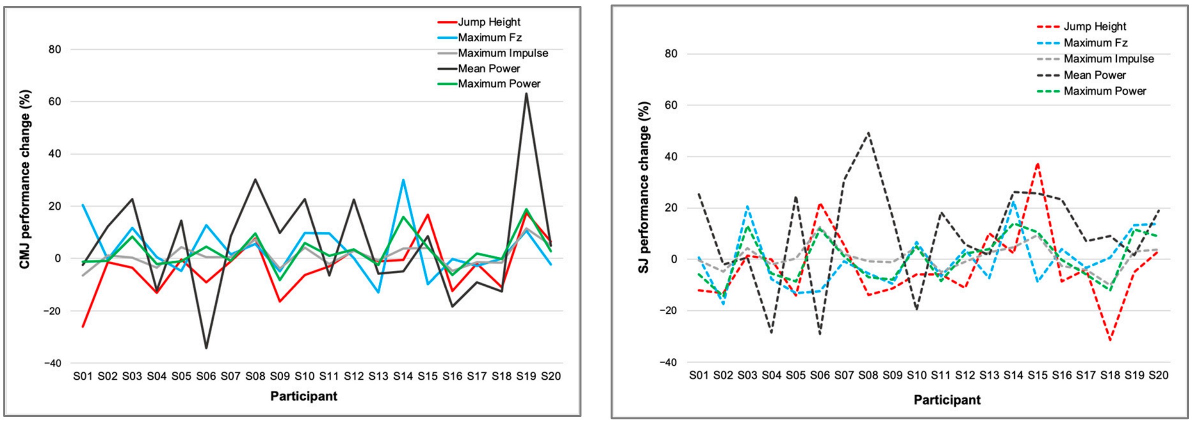
Table 4 presents the results on the lower limb explosive performance and the effect size due to training for all athletes. Due to the non-statistically significant training intervention by the sex interaction effect in any parameter, the results refer to a paired-sample *t* test analysis. There was no significant change due to training intervention, either in the CMJ's or the SJ's height (CMJ: $p = 0.134$, SJ: $p = 0.303$), maximum vertical force (CMJ: $p = 0.255$, SJ: $p = 0.708$), maximum impulse (CMJ: $p = 0.313$, SJ: $p = 0.449$), and mean (CMJ: $p = 0.988$, SJ: $p = 0.088$) and maximum mechanical power (CMJ: $p = 0.219$, SJ: $p = 0.879$).

Table 4. Parameters of lower limb explosive performance before (PRE) and after (POST) the combined balance and multidirectional plyometric training intervention.

Parameter	Jump	PRE	POST	%Δ	Cohen's d
Jump height (cm)	CMJ	20.4 ± 4.4	19.6 ± 3.8	−3.9%	0.18
Maximum vertical force (N)		1023 ± 275	1051 ± 271	+2.7%	0.10
Maximum impulse (N·sec)		104 ± 30	105 ± 30	+1.0%	0.04
Mean power (Watt)		190 ± 81	190 ± 64	0%	0.02
Maximum power (Watt)		1764 ± 578	1797 ± 561	+1.5%	0.06
Jump height (cm)	SJ	17.3 ± 3.5	16.7 ± 3.6	−3.5%	0.16
Maximum vertical force (N)		1115 ± 271	1104 ± 275	−1.0%	0.04
Maximum impulse (N·sec)		97 ± 27	97 ± 27	0%	0.03
Mean power (Watt)		369 ± 136	401 ± 148	+8.7%	0.23
Maximum power (Watt)		1743 ± 524	1737 ± 499	−0.3%	0.01

%Δ: Post- vs. pre-measurements. Data are mean ± SD.

Figure 2 depicts the individual percent change in the explosive performance parameters of each jump due to the effect of the combined training intervention in the preadolescent soccer athletes.



(**a**) (**b**)

Figure 2. Individual change (%Δ: post- vs. pre-measurement) in lower limb explosive performance during jumping ((**a**): CMJ, (**b**): SJ) in the preadolescent soccer athletes (note: to facilitate visual inspection of the graphs, the first 10 series of data refer to the male and the next 10 series of data to the female soccer athletes).

4. Discussion

The purpose of this study was to examine the effect of combined balance and multidirectional plyometric training in male and female preadolescent soccer athletes. Overall, the results did not confirm the main hypothesis since the postural balance ability and the lower limb explosive performance of athletes did not show a significant improvement post-training. Further, the absence of a significant interaction between training and visual restriction leads to the rejection of the hypothesis, referring to the possible benefit of the training intervention in processing visual information for postural control regulation in preadolescent soccer athletes.

The present findings show that the combined training intervention resulted in a significant deterioration of static two-legged balance due to a 39% increase in the anteroposterior CoP sway range. On the other hand, the CoP path length and mediolateral sway range showed a non-statistically significant increase by 6.4% and 36%, respectively, whereas single-legged static balance performance was found to be slightly, albeit not significantly, improved after training. In the literature, no studies combining balance and plyometric training could be found in soccer, except for two recent studies in other team sports. In particular, and in agreement with our findings, no significant change was found in single-legged quiet stance balance ability in 15–16-year-old female regional-level basketball athletes following 8-week combined balance and plyometric training [27]. On the contrary, an improvement in dynamic anteroposterior and mediolateral CoP sway was seen after landing either from a horizontal or a lateral jump for short distance (40% of height) in elite male badminton players, who participated in a combined intervention (6 weeks at a frequency of 3 days/week for 1 h) [41]. In the present study, the training volume was the result of balance and plyometric training exercises, but in that study [41], plyometric training was twice the volume of the respective balance training's volume. Moreover, the present findings on static balance performance are in disagreement with a previously reported training intervention (8 weeks, 24 sessions) [21], which had several similarities in reference to balance exercises and dynamic stabilization tasks as the ones administered in the current study (see Table 1). In that study [21], an enhancement by approximately 38% and 25% was reported for static and dynamic balance in the dominant leg of adolescent (12–13 years old) male soccer players. Similarly, the static, semi-dynamic as well as dynamic balance in younger (9–11 years old) male soccer athletes was enhanced following their participation in a 12-week balance training, comprising static one- and two-legged balance tasks, semi-dynamic balance tasks, along with walking and running on both stable and unstable surfaces [16]. Further, in elite junior (aged 16.0 ± 0.5 years) male soccer players who were involved for 10 weeks at a frequency of twice a week in plyometric unloaded versus ankle-loaded (2.5% of body weight) training, there was an improvement in the stork balance time score performed with open eyes in both groups [42]. Previous 6- to 8-week training interventions that have used a plyometric training protocol combining horizontally and vertically directed jumps found a decrease in the anteroposterior and mediolateral sway range by approximately 15% and 19% during two-legged static balance tasks with open and closed eyes in 9–13-year-old male soccer players [11], while an improved dynamic balance ability was seen in male soccer athletes of similar age to our athletes as well as in older ones [9,10].

The disparity between the present findings and those previously reported might be attributed to the heterogeneity of training regimens. Training volume was higher in most of those studies [9,16,21,37,38], as compared to the current study. Solely, Ramirez-Campillo et al. [11] implemented the same training volume (i.e., 12 sessions for a frequency of training twice/week). However, their intervention consisted of a combination of horizontal and vertical jumps, which amounted to a greater total number of plyometric jumps. The difference in the plyometric training stimulus might explain the absence of changes in static balance ability that was observed here, since a meta-analysis concluded that plyometric training interventions have a significant but small effect size on static and dynamic balance performance [43].

Moreover, it has been shown that the transfer of postural balance adaptations is strongly associated with the context in which the physical activity or sport is practiced [13]. It is highly likely that differences in the content of balance exercises used in previous studies [16,21,42] could account for the observed disparity in results. Similar to Bouteraa et al. [27] and Lu et al. [41], who subjected their athletes to a combined balance and plyometric training intervention, our soccer athletes practiced single-legged static stance tasks and dynamic displacements both on various bases of support and types of support surfaces (see Table 1). Even though the present results suggest a trend towards a slight improvement in single-legged balance performance, since CoP parameters were decreased by 0.2 to 1.9%, this study's training stimulus was probably not adequate to bring about significant changes, as previously reported [16,21,41,42].

Static balance assessment based on CoP measures is considered as a reliable method to examine postural steadiness [31,33–37]. With the exception of Cè et al.'s study [16], previous authors, who have found improvements in static balance ability [21,42], assessed performance based on the time score. It can be acknowledged that the time to complete a single- or two-legged balance task is very different to the CoP oscillations, which are being recorded within that same time period and reflect the center-of-mass effort to generate a corrective torque in order to counter the destabilizing gravitational torque [24]. Lu et al. [41] also assessed CoP sway by means of recording the vertical ground reaction force, but their positive results refer to dynamic balance performance, thus limiting any direct comparison with the current findings.

Plyometric training is a widely recognized method to improve and maximize muscle strength and power. As mentioned, the present combined training regimen did not induce any significant effect on the parameters determining the lower limb explosive performance. However, the current findings showed a small ($p > 0.05$) improvement in maximum force, maximum impulse and maximum power in the CMJ task (1.0–2.7%) and a greater non-statistically significant change in mean power (+8.7%) in the SJ task, whereas jump height was decreased (−3.5 to −3.9%). Quite a large number of studies have focused on jump height, the reason being that it is probably the most frequently chosen parameter for assessing lower limb explosive performance. Evidence of a moderate-to-large effect size of plyometric training on jump height has been previously reported, regardless of athletes' sex [43], and a small-to-large effect size has been found for female athletes [44]. In contrast with the present findings, a positive effect of short-term (6–8 weeks) plyometric multidirectional training has been shown in male [9,10] and female soccer athletes [11,12] on CMJ and SJ height. Recently, it was argued that interventions ranging from 400 to 600 min of total duration are required in order to achieve the maximization of the plyometric training effect on vertical jump height during adolescence [45]. Even if these suggested optimal intervention durations were scaled to our preadolescent athletes, the total duration of the plyometric part of the current study's combined intervention would still be considerably shorter, as it amounted to approximately 88 min. It is highly likely that the lesser, by 1/6 plyometric, training stimulus here, as compared to the recommended optimal one, accounts for the observed decrease in CMJ and SJ height.

On the other hand, the results showed a tendency towards an improvement in maximum force, impulse and power in the CMJ and in mean power in the SJ, respectively. It has been theoretically and experimentally argued and examined in vivo for the vastus lateralis muscle that jump height does not constitute the most appropriate parameter for the assessment of the maximal force and power-generating capacity of the lower limbs in systematically trained individuals [46,47]. The production of mechanical power during the propulsion phase of the jump, which will potentially affect the achieved jump height, is determined to a considerable extent by intrinsic neuromuscular mechanisms and, in particular, by the force–length, power–velocity and force–velocity potential. The athletes received specific instructions about how to execute the CMJ and SJ tasks with regard to fully extending their lower limb joints during the propulsion phase [38]. Assuming that their lower limb muscles were maximally activated, as they were also instructed to perform maximum-effort jumps, the lower limb joints' excursion corresponds to the distance over which muscles will generate force and mechanical power, and, thus, it could be hypothesized that all athletes operated on a similar portion of their individual force–length curve.

Based on the proposed maximum dynamic output hypothesis, the optimum loading condition for maximizing power output during jumping is one's own body [48,49]. It has been suggested that due to individual neuromuscular characteristics and training history, some athletes will need a positive load (that is, an additional load to their body mass) and some others a negative one (that is, an assistance to decrease loading) in order to ensure optimal loading conditions [46]. The athletes had similar training history since they trained in the same sport club during the last 2–3 years. While the assessment of biological maturation did not present any statistically significant difference, the inspection of individual values showed that nine (five male and four female athletes) out of the twenty athletes had already achieved their peak height velocity by approximately 0.7 years at the end of the training intervention. These inter-individual differences in the maturation process of the male and female soccer athletes along with a 23% variation in their body mass suggest a differentiation in the jumps' optimal loading conditions and could probably justify the slight trend ($p > 0.05$) towards the improvement in lower limb explosive performance post-training (see Figure 2). It has been found that vertical jumping performance differs between boys and girls from 14 years onwards due to changes mainly in leg length and the respective lean muscle volume [50]. Leg length was significantly increased by 1% for the whole sample after the intervention. A greater change in leg length of the nine biologically more mature athletes could be a possibility that, if true, could imply a considerable variation between the responses of the biologically more mature as compared to their less mature teammates. This inter-individual variation might have resulted in the absence of a significant overall training effect.

Each sport's postural requirements, in combination with the athlete's systematic practice on the sport's motor patterns, are capable of modifying one's degree of dependence on the sensory systems responsible for the regulation of postural control and balance [13]. We hypothesized that the athletes' practice in static balancing conditions under the restriction of vision could be beneficial to them with regard to their reliance on this source of sensory information for balance achievement and/or maintenance. A significant interaction was solely found for the anteroposterior CoP sway range in the two-legged stance task, where the decrease between restriction and no restriction of vision condition pre- training was followed by an increase post-training (see Figure 1B). No significant interaction was found in the other CoP parameters in the two-legged task as well as in any examined CoP parameter in the one-legged balance task. Overall, these findings suggest that the combined balance and MPT intervention did not contribute to shifting the reliance of athletes to a greater extent on other sources of sensory input (e.g., proprioception) for their balance control. This is in disagreement with a previously reported significant improvement in two-legged balance with eyes open by −16.2% and with eyes closed by −18.7% in the anteroposterior CoP sway and by −14.8% and −17.3% with eyes open and closed, respectively, in the mediolateral CoP sway found in male soccer players aged 11.2 ± 2.3 years old [11]. As mentioned already, that training intervention used plyometric exercises with horizontal and vertical jumps [11]. During a vertical and horizontal jump, there exist specific kinematic requirements for the body's center of mass during the propulsion phase in order to perform the jump with as much of an optimal coordination strategy as possible [51]. It is probable that the greater plyometric training load in that study was transferred to those athletes' ability to more efficiently regulate their body's position, hence the improvement in static balance [11].

There exists neurophysiological evidence suggesting that the contribution of vestibular and proprioceptive sensory information increases during the process of postural regulation as a function of the competitive level, while the contribution of visual information decreases [14,15]. Elite and expert soccer players were shown to have a lower reliance on vision and a higher temporal dedication of their eye movements in processing game-related information, as compared to lower-level non-expert players [14,15,52]. Thus, when a player uses the time required to process visual information for performing their own motor actions (e.g., body positioning regulation, ball control), one then reduces the available time to analyze the game and make strategic decisions about offense or defense [15]. In the present study, the limited training experience of the athletes combined with the short-term training stimulus most probably suggest the absence of a training by vision interaction effect, since the preadolescent male and female athletes were not equipped with such a competitive and/or expertise level to efficiently engage their vestibular and/or proprioceptive systems in the regulation of balancing tasks while their vision was being restricted.

A final note is dedicated here with regard to the study's secondary purpose that was related to a possible training intervention by sex interaction effect. As reported in the results, the statistical analyses did not yield a significant interaction effect in any balance or lower limb explosive performance measure. Taking into consideration the fact that most of the previous related work has examined male athletes [9–11,16,21,41,42], it would have been interesting to present a comparison based on sex. However, the absence of any interaction effect suggested that male and female preadolescent athletes responded in a similar manner to the combined training intervention, and, for that reason, respective results were not presented. Neurophysiological adaptations have been reported to be induced by balance training [53], whereas plyometric training can elicit neuromuscular responses [54]. However, a significant interference of gender with the effect of plyometric training on balance performance was not found in a recent meta-analysis [55]. On the other hand, young female athletes were previously reported to show greater adaptive responses when plyometric training interventions were of longer duration (>16 sessions), had greater weekly training frequency (>2 times) as well as longer durations in each session (≥30 min) [56]. This study's short-term training stimulus in combination with the inter-individual differences in the athletes' estimated biological maturation might justify the absence of different responses between the male and female soccer athletes.

There are several limitations to be considered in this study. A main limitation was not evaluating the training load, since, despite the inclusion criteria requiring that the athletes had participated in 80% of the team's training sessions in the last 3 months before the start of the study, the observed variation in biological maturity status among the athletes cannot exclude the possibility that the training load was perceived as low for some athletes and as high for some others. Another important limitation is that the menstrual cycle of the female athletes was not controlled for. Even though the age range of the athletes fell within the time period where menarche typically occurs (10–16 years of age), a record and attempt to measure them at the same stage of their menstrual cycle post-training should have been made. Further, the sample team was competing in a regional soccer league, which probably implies that a part of the soccer training was specific to their playing position. Static balance was not assessed in relation to playing position due to the small sample size. Therefore, the possibility that the absence of a significant training intervention effect might be partly related with a variation in balance performance as a result of playing position-related training-induced postural adaptations [57,58] should be considered.

5. Conclusions

In conclusion, the short-term 6-week combined balance and multidirectional plyometric training was not effective in improving the static balance and lower limb explosive performance in preadolescent male and female soccer athletes. It is recommended that a training intervention of higher training volume and based on individualized training load using similar balance, dynamic stabilization tasks and multidirectional plyometric exercises be further investigated in preadolescent soccer players according to playing position.

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