European Journal of Applied Physiology (2024) 124:2591–2601
https://doi.org/10.1007/s00421-024-05477-4

ORIGINAL ARTICLE

Effects of vertical and horizontal plyometric training on jump performances and sprint force–velocity profile in young elite soccer players

Florian Norgeot[1,2] · **Alexandre Fouré**[1]

Received: 15 December 2023 / Accepted: 22 March 2024 / Published online: 11 April 2024

Abstract

Purpose During a soccer match, horizontal acceleration ability during short sprints is determinant for performance. Development of sprint force and velocity qualites have been reported after plyometric training. However, orientation of plyometric training exercises can influence the functional performance. The purpose of this study was to compare the horizontal and vertical orientation of plyometric training on explosiveness performances and sprint force–velocity profile in young soccer players.

Methods Twenty-eight soccer players were recruited and divided in two groups: vertical (VG, $n=14$) and horizontal (HG, $n=14$) groups. Tests including jumps and sprint performances were conducted before and after the 8 week training period. Sprint force–velocity profile (FVP) was evaluated during a 30 m sprint test.

Results The results demonstrated significant improvements in both VG and HG for jump performances (from + 4.9% to + 9.0%), sprint times (from −5.5% to −8.7%) and FVP parameters. Higher relative changes for the HG than for the VG were observed in 5 m and 15 m sprint times, horizontal jump lengths, and also in FVP parameters, especially improvements in maximal power (VG: + 16.4% *vs.* HG: + 28.1%) and in the decrease rate of horizontal orientation of force with increasing speed (HG: + 22.9%) during the 30 m sprint.

Conclusions Both horizontal and vertical plyometric training can be either used in young soccer players to improve vertical and horizontal performances in jump and sprint. However, horizontal plyometric training may result in a greater improvement in horizontal ballistic actions while similarly developing vertical jump qualities compared to vertical plyometric training in young soccer players.

Keywords Stretch–shortening cycle · Plyometrics orientation · Team sports

Abbreviations

ANOVA	Analyse of variance
CMJ	Counter movement jump
CT	Contact time
CV	Coefficient of variation
DJ	Drop jump from 30 cm
DRF	Slope of the force ratio—velocity relationship
F_0	Maximum force of the force–velocity modeling from 30 m linear sprint
FVP	Force–velocity profile
HG	Horizontal group
MDC	Minimal detectable change
P_{max}	Theoretical maximum power
RF_{max}	Maximal ratio of force
RSI	Reactive strength index
SJ	Squat jump
V_0	Maximum velocity of the force–velocity modeling from 30 m linear sprint
VG	Vertical group

Communicated by Olivier Seynnes.

✉ Alexandre Fouré
alexandre.foure@hotmail.fr

1 Universite Claude Bernard Lyon 1, Laboratoire Interuniversitaire de Biologie de la Motricité (LIBM), UR7424, Villeurbanne, France

2 Football Bourg-en-Bresse Péronnas 01, 01960 Péronnas, France

Introduction

During a soccer match, 83% of goals are preceded by an explosive action, often involving a straight-line sprint, a jump, or a change of direction (Faude et al. 2012). Given that 90% of sprints are shorter than 20 m during a soccer match (Vigne et al. 2010), the acceleration phase becomes crucial. Propulsion forces have a key role in sprint performance during the acceleration phase and are also significant for executing changes of direction (von Lieres and Wilkau et al. 2020).

The plyometric training is recognized for its ability to enhance muscle power necessary for explosive movements (Wilson and Flanagan 2008). However, the main focus of plyometric training protocols is primarily on exercises with a dominant vertical component, while the benefits on motor task involving a significant horizontal component remain contrasted. For instance, seven weeks of vertical plyometric training have improved countermovement jump performance, but did not result in any significant changes in 20 m sprint time (Ramirez-Campillo et al. 2014). Considering that 95% of soccer actions involves horizontal force production (Young 2006), the use of horizontal plyometric exercises could be particularly advantageous for enhancing sprint performances (Saez de Villarreal et al. 2012).

While some studies comparing the effects of vertical and horizontal orientations in plyometric training exercises have found no significant difference in the ability to change direction, as well as jump and sprint performances (Ramirez-Campillo et al. 2015), others studies have demonstrated specific benefits (Loturco et al. 2015; Dello Iacono et al. 2017). Horizontal plyometric training has been shown to enhance sprint performance and changes of direction, whereas vertical plyometric training has led to improvements in jump performances (Loturco et al. 2015; Dello Iacono et al. 2017). It is noteworthy that the specific influence of the relative orientation of horizontal force in the anterior and lateral direction during plyometric exercises on linear sprint performance and change of direction remains underexplored.

While sometimes prone to over-interpretation (Ettema 2024), force–velocity profile (FVP) allows to qualitatively estimate athletes' behavior during a sprint (Samozino et al. 2022), particularly in younger soccer players (Zhang et al. 2021; Fernandez-Galvan et al. 2021). The FVP can also evaluate the plyometric training-induced effects on the changes in sprint performance and athletes' behavior during a linear sprint (Barrera-Dominguez et al. 2023; Watkins et al. 2021). However, a comparison between horizontal and vertical plyometric training on sprint FVP has yet to be conducted. These findings highlight the importance of accurately assessing the specific benefits of horizontal and vertical plyometric training, particularly in young soccer players, with regard to sprint FVP.

The aim of this study was to evaluate and compare the effects of 8-week vertical and horizontal plyometric training on jump performances and sprint FVP in young soccer players. Through the assessment of sprint FVP, the primary hypothesis suggesting that horizontal plyometric training would be more effective than vertical training in improving sprint performance and the ability to change direction in highly skilled young soccer players was tested.

Materials and methods

Study population

Twenty-eight participants, soccer players at the highest regional level, were recruited between December 2020 and April 2021. They were separated in two trained groups performing vertical (VG | $N = 14$ | age: 14.5 ± 0.5 y [14—15], height: 170 ± 7 cm [153—176], body mass: 57 ± 9 kg [40 – 68]) and horizontal (HG | $N = 14$ | age: 14.5 ± 0.5 y [14—15], height: 167 ± 7 cm [153—175], body mass: 56 ± 9 kg [40—69]) plyometric training. A reproducibility group composed of young soccer players with similar anthropometric characteristics was also recruited ($N = 14$) to assess the measurements variability over a nine weeks period (Table 1). The number of participants was chosen based on a statistical power calculation ($\alpha = 0.05$ and $1\text{-}\beta = 0.8$) considering the variability of measurement observed in pilot experiments and reproducibility results. On that basis, a medium effect size ($\eta^2_p = 0.06$) after the training can be robustly detected. Our study was approved by the local ethical research committee and participants were fully informed about the nature and the aim of the study. They all gave their informed written consent to participate in this study conducted in conformity with the last version of the Declaration of Helsinki. Participants were included on the basis of the lack of affection after clinical interrogation, with no known musculoskeletal, articular, or cardiovascular dysfunction or abnormalities, chronic or central neurological disease and medication.

Experimental design

Pre-tests and post-tests were set up to assess the effects of an 8-week plyometric training program (*i.e.*, vertical or horizontal), with 2 sessions per week in a progressive manner (Table 2). Participants were tested in a single session in several tests performed in a randomized order: (*i*) vertical and horizontal jump tests determining performances in squat jump (SJ), counter movement jump

Table 1 Reproducibility results obtained between two tests over a 9-week period for sprint performances and force–velocity parameters, and jump performances

		CV (%)	MDC
Sprint performances	Time 5 m/10 m/15 m/30 m (s)	[0.5–3.6]	0.11
	F_0 (N/kg)	7.8	1.44
	V_0 (m/s)	3.9	0.84
	P_{max} (W/kg)	4.0	2.01
	DRF	11.9	− 0.03
	RF_{max} (%)	3.5	4.53
Vertical jump performances	SJ (cm)	3.0	2.85
	CMJ (cm)	2.6	2.17
	DJ (cm)	6.0	6.06
Horizontal jump performances	SJ (m)	2.0	0.08
	CMJ (m)	1.6	0.08
	DJ (m)	1.4	0.08
	5-jumps (m)	3.2	0.87

F_0 Maximum force of the force–velocity modeling from 30 m linear sprint, V_0 Maximum velocity of the force–velocity modeling from 30 m linear sprint, P_{max} Theoretical maximum power, DRF Slope of the force ratio—velocity relationship, RF_{max} Maximal ratio of force

SJ squat jump, *CMJ* counter-movement jump, *DJ* drop jump, *CT* ground contact time, *RSI* reactive force

(CMJ), drop jump with a 30 cm drop height (DJ) and a horizontal five jumps (5-jumps); (*ii*) a force–velocity profile (FVP) assessed from a 30 m sprint (*iii*) a change of direction test on a short distance running with 4 direction changes. All of the trained participants performed the test session before (pre-test) and 1 week after (post-test) the end of the training period. The reproducibility of the measurements was assessed with two similar tests separated by a 9-week period.

Training protocol

During the 8 week plyometric training, both trained groups (*i.e.*, VG and HG) performed 2 sessions per week in a progressive manner for a total of 2000 vertical or horizontal contacts (Table 2). All the exercises were performed with the instruction to have the shortest ground contact time. The vertical plyometric training consisted of hurdle jumps at different heights (*i.e.*, 15, 30 and 45 cm) and vertical CMJ. Vertical jumps were performed on two feet (*i.e.*, hurdle jumps and CMJ) and on a single leg for unilateral hurdle jumps exercise (Table 2). To avoid an excessive horizontal component, the hurdles were spaced 30 cm apart for each exercise to promote vertical rather than horizontal displacement during the jumps. The horizontal plyometric training was composed of bouncing strides (*i.e.*, anterior jump from one foot to the other) and lateral jumps (*i.e.*, lateral jump from one foot to the other). Unilateral bouncing strides were performed on a single leg. The distance between jumps increased progressively (*i.e.*, from 60 to 270 cm).

Jump performances

A warm-up was based on athletic routines including skipping, heel-buttocks, step-ups, proprioception movements and lunges. For all jump tests, hands were placed on hips.

Vertical SJ, CMJ and DJ performances were assessed from time flight measurements using an *Optojump* (Optojump Next, Microgate, Bolzano, Italy). Initial SJ position was knee flexed at 90° and was performed with no countermovement. During the vertical DJ (*i.e.*, 30 cm high), both maximal vertical height and ground contact time (CT) were evaluated. A reactive strength index (RSI) was then calculated from the ratio between jump height and ground contact time (Haynes et al. 2019).

Horizontal SJ, CMJ and DJ performances were assessed from *My Jump* (v.6.1.2) application (Balsalobre-Fernandez et al. 2015). Horizontal jump videos were acquired at 29.98 frames/s. An additional 5-jumps test was also performed and measured with a decameter tape with the back of the foot as a reference. CT and RSI were also assessed from horizontal DJ.

Change of direction

The change of direction performance was evaluated from a specific test (Cazorla et al. 2008) (*i.e.*, 20 m distance with four changes of direction) using photoelectric cells (Brower TC PhotoGate, *Brower Timing Systems*, Draper, United States of America).

Table 2 Plyometric trainings in vertical and horizontal groups.

Week	Session	Vertical group ($n = 14$)	Horizontal group ($n = 14$)
1	1	8×5 bilateral HJ (15 cm) 8×5 CMJ	8×5 bouncing strides (free) 8×5 lateral jumps (free)
	2	8×5 bilateral HJ (15 cm) 8×5 CMJ	8×5 bouncing strides (120 cm) 8×5 lateral jumps (90 cm)
2	3	8×5 bilateral HJ (15 cm) 8×5 CMJ	8×5 bouncing strides (120 cm) 8×5 lateral jumps (100 cm)
	4	10×4 unilateral HJ (15 cm) 10×4 CMJ	10×4 bouncing strides (140 cm) 10×4 unilateral strides (90 cm)
3	5	10×4 unilateral HJ (15 cm) 10×4 CMJ	10×4 bouncing strides (free) 10×4 unilateral strides (free)
	6	10×4 bilateral HJ (15 cm) 10×4 CMJ	10×4 bouncing strides (140 cm) 10×4 lateral jumps (100 cm)
4	7	10×6 unilateral HJ (15 cm) 10×6 CMJ	10×6 bouncing strides (140 cm) 10×6 unilateral strides (120 cm)
	8	10×6 bilateral HJ (30 cm) 10×6 CMJ	10×6 bouncing strides (180 cm) 10×6 lateral jumps (120 cm)
5	9	10×7 unilateral HJ (30 cm) 10×7 CMJ	10×7 bouncing strides (180 cm) 10×7 unilateral strides (130 cm)
	10	10×7 unilateral HJ (30 cm) 10×7 CMJ	10×7 bouncing strides (210 cm) 10×7 unilateral strides (free)
6	11	10×7 bilateral HJ (30 cm) 10×7 CMJ	10×7 unilateral strides (140 cm) 10×7 lateral jumps (140 cm)
	12	10×8 unilateral HJ (30 cm) 10×8 CMJ	10×8 bouncing strides (240 cm) 10×8 unilateral strides (free)
7	13	10×8 unilateral HJ (30 cm) 10×8 CMJ	10×8 bouncing strides (240 cm) 10×8 unilateral strides (150 cm)
	14	10×8 bilateral HJ (45 cm) 10×8 CMJ	10×8 bouncing strides (240 cm) 10×8 lateral jumps (140 cm)
8	15	10×9 bilateral HJ (45 cm) 10×9 CMJ	10×9 bouncing strides (240 cm) 10×9 lateral jumps (140 cm)
	16	10×10 unilateral HJ (45 cm) 10×10 CMJ	10×10 bouncing strides (270 cm) 10×10 lateral jumps (180 cm)
Total		**2000 contacts** (27% unilateral)	**2000 contacts** (72% anterior | 28% lateral)

Data are expressed as number of contacts (series × jumps) and intensity are displayed between parentheses (jump height [for vertical group] or length [for horizontal group] in centimeters). Unilateral jumps were made on a single leg (and repeated on the other)

HJ hurdle jump, *CMJ* counter movement jump

Sprint force–velocity profile

A warm-up was performed including straight line sprints with increasing intensity, slalom workshops, and active dynamic stretching. Each test was performed three times by each participant and the best achievement was considered for analyses.

From a linear 30 m sprint, times at 5, 10, 15 and 30 m were quantified from *My Sprint* (v.2.0) application (Romero-Franco et al. 2017) and FVP was assessed for each participant, from a theoretical F-V relationship modeling of the 30 m linear sprint (Samozino et al. 2022). The maximum force (F_0), maximum velocity (V_0), maximum power (P_{max}), maximal ratio of force (RF_{max}, maximal ratio of the step-averaged horizontal component of the ground-reaction force to the corresponding resultant force) and the decrease rate in RF with increasing speed (DRF, slope of the linear RF-velocity relationship) were characterized (Morin and Samozino 2016; Samozino et al. 2022).

Statistical Analyses

The normality of the data distributions was checked using Shapiro–Wilk test. The reproducibility results were reported in Table 1 with coefficient of variation (CV) and minimal detectable change (MDC). A two-way repeated measures analysis of variance (group × time) was used to determine the effects of the chronic intervention on jump performances, FVP parameters and change of direction time in both vertical and horizontal groups. Tukey HSD test was used as post-hoc tests when appropriate. Mauchly's sphericity test was performed and Greenhouse–Geisser correction was applied when necessary. A student t-test was also used to assess the change in performance in each group and to compare the relative changes in all the variables between the trained groups. When the normality of the data distribution was not verified (*i.e.*, for anthropometric variables), a non-parametric Kruskal–Wallis or Friedmann test was performed. All the tests were performed using R-Commander software (2.6–0, *GNU General Public License*, Hamilton, Canada). Effect size was also assessed from partial eta squared (η^2_p) for the significant results retrieved from ANOVA and using Cohen's *d* for post-hoc analysis and Student t-test comparison. Small, medium and large effect sizes were reported at the threshold values of 0.01, 0.06 and 0.14 for η^2_p and 0.2, 0.5 and 0.8 for Cohen's *d* (Cohen 1969). The *p* value was fixed at 0.05 and the results were reported as mean ± standard deviation (SD) in tables and figures.

Results

Jump performance

Both VG and HG groups improved performance in SJ (VG: + 8.7% | HG: + 10.2%), CMJ (VG: + 5.0% | HG: + 5.9%) and DJ (VG: + 11.5% | HG: + 7.5%) with no difference between VG an HG ($p > 0.05$). No difference was observed for CT and RSI during the vertical DJ ($p > 0.05$) (Table 3).

Horizontal performances were improved in CMJ (VG: + 5.6% | HG: + 8.6%) and DJ (VG: + 5.8%, $p = 0.003$, $d = 0.576$ | HG: + 9.8%, $p = 0.001$, $d = 1.127$). Horizontal SJ performance was significantly improved in HG (+ 8.6%, $p = 0.001$, $d = 0.868$) as well as 5-jumps length (+ 2.3%, $p = 0.016$, $d = 0.690$). CT and RSI determined during the horizontal DJ were unchanged after the training period for the two experimental groups ($p > 0.05$, Table 4). Relative changes after the training period were significantly higher in HG than in VG in horizontal SJ ($p = 0.043$, $d = 0.670$) and horizontal DJ ($p = 0.045$, $d = 0.655$) performances (Fig. 1).

Change of direction performance

No significant change was found in the change of direction performance for both VG and HG ($p > 0.05$, Table 5).

30-m sprint force–velocity profile

Sprint times were decreased in both VG and HG after 5 m (VG: + 6.7% | HG: + 12.4%), 10 m (VG: + 5.6% | HG: + 8.2%), 15 m (VG: 4.7% | HG: + 9.1%) and 30 m (VG: + 4.8% | HG: + 6.0%) (Table 5). The relative decrease in sprint time was significantly higher in the HG than in VG at 5 m ($p = 0.010$, $d = 0.942$) and 15 m ($p = 0.001$, $d = 0.717$) (Fig. 1).

Concerning the FVP parameters, a significant interaction was found for RF_{max} ($p = 0.037$, $\eta^2_p = 0.157$). Both groups significantly improved F_0 (VG: + 13.1%, $p = 0.003$, $d = 1.139$ | HG: + 26.5%, $p = 0.0003$, $d = 1.526$ | Fig. 2A), P_{max} (VG: + 15.9%, $p = 0.001$, $d = 1.304$ | HG: + 27.0%,

Table 3 Vertical jump performances before (Pre-test) and after (Post-test) the 8-week plyometric training for the vertical (VG) and horizontal (HG) groups

		Group	Pre-test	Post-test	Statistical effects	
SJ	Height (cm)	VG	31.1 ± 6.3	33.5 ± 5.1[a]	Time effect $\eta^2_p = 0.623$ $p = 0.001$	$p = 0.001$ $d = 0.410$
		HG	29.8 ± 3.0	32.7 ± 2.8[a]		$p = 0.001$ $d = 0.994$
CMJ	Height (cm)	VG	32.5 ± 5.8	33.9 ± 5.3[a]	Time effect $\eta^2_p = 0.333$ $p = 0.001$	$p = 0.025$ $d = 0.254$
		HG	33.1 ± 3.2	32.9 ± 3.2[a]		$p = 0.005$ $d = 0.548$
DJ	Height (cm)	VG	33.7 ± 6.2	37.0 ± 5.2[a]	Time effect $\eta^2_p = 0.348$ $p = 0.001$	$p = 0.009$ $d = 0.557$
		HG	33.6 ± 4.6	35.9 ± 3.9[a]		$p = 0.010$ $d = 0.532$
	CT (s)	VG	0.28 ± 0.07	0.30 ± 0.08	*ns*	/
		HG	0.28 ± 0.06	0.29 ± 0.06		/
	RSI (cm s^{-1})	VG	123.6 ± 28.1	129.8 ± 26.3	*ns*	/
		HG	124.3 ± 27.7	129.2 ± 28.2		/

SJ squat jump, *CMJ* counter-movement jump, *DJ* drop jump, *CT* ground contact time, *RSI* reactive force

[a]significantly different from Pre-test ($p < 0.05$), $\eta^2 p$ partial eta squared (from ANOVA main effect), *d* Cohen's d (from Student t-test), *ns* non-significant

Table 4 Horizontal jump performances before (Pre-test) and after (Post-test) the 8-week plyometric training for the vertical (VG) and horizontal (HG) groups

		Group	Pre-test	Post-test	Statistical effects	
SJ	Length (m)	VG	1.67 ± 0.20	1.72 ± 0.14	*Time effect*	*ns*
		HG	1.59 ± 0.17	1.71 ± 0.11[a]	$p = 0.001$ $\eta^2_p = 0.365$	$p = 0.002$ $d = 0.868$
CMJ	Length (m)	VG	1.72 ± 0.20	1.81 ± 0.17[a]	*Time effect* $p = 0.001$	$p = 0.001$ $d = 0.486$
		HG	1.63 ± 0.16	1.77 ± 0.15[a]	$\eta^2_p = 0.692$	$p = 0.001$ $d = 0.876$
DJ	Length (cm)	VG	1.92 ± 0.17	2.03 ± 0.21[a]	*Time effect* $p = 0.001$	$p = 0.003$ $d = 0.576$
		HG	1.88 ± 0.17	2.06 ± 0.14[a]	$\eta^2_p = 0.675$	$p = 0.001$ $d = 1.127$
	CT (s)	VG	0.36 ± 0.07	0.36 ± 0.08	*ns*	/
		HG	0.34 ± 0.08	0.34 ± 0.04		/
	RSI ($cm \cdot s^{-1}$)	VG	5.56 ± 1.33	5.77 ± 1.16	*ns*	/
		HG	5.84 ± 1.61	6.25 ± 1.03		/
5-jumps	Length (m)	VG	10.79 ± 1.11	11.00 ± 1.05	*Time effect*	*ns*
		HG	10.46 ± 1.08	11.08 ± 0.67[a]	$p = 0.005$ $\eta^2_p = 0.270$	$p = 0.016$ $d = 0.690$

SJ squat jump, *CMJ* counter-movement jump, *DJ* drop jump, *CT* ground contact time, *RSI* reactive force

[a]significantly different from Pre-test ($p < 0.005$), $\eta^2 p$ partial eta squared (from ANOVA main effect), *d* Cohen's d (from Student t-test), *ns* non-significant

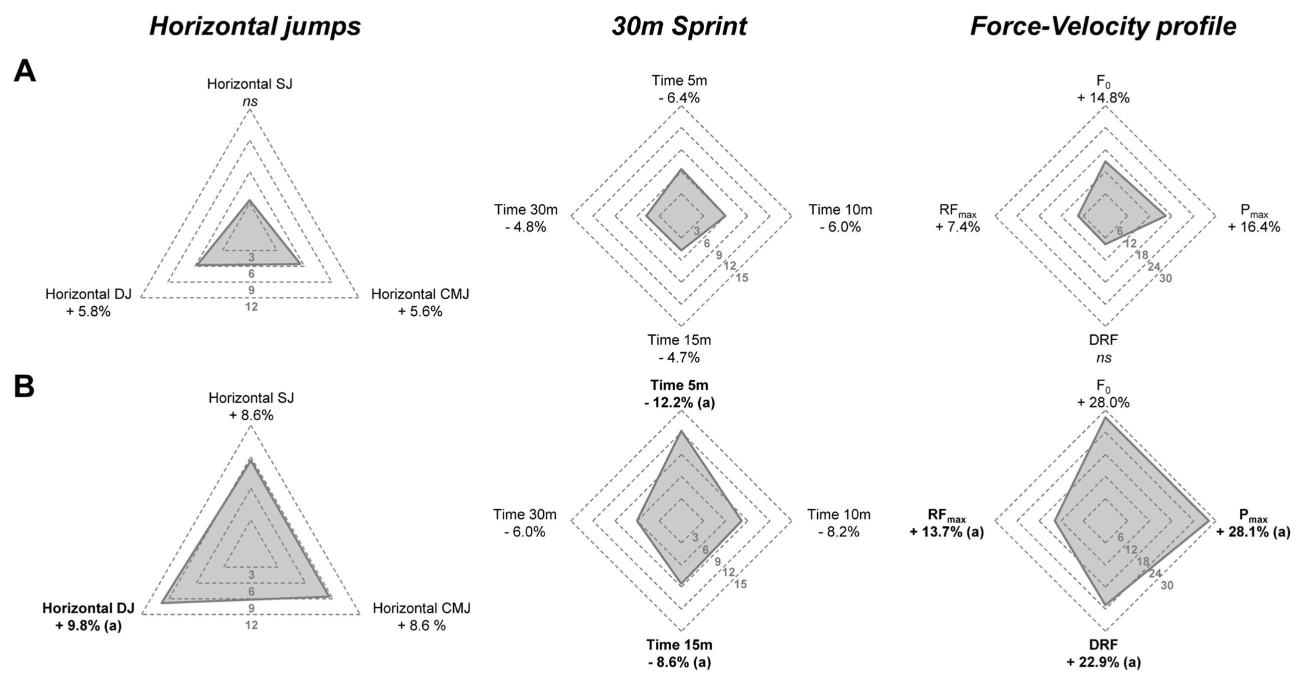

Fig. 1 Significant mean relative changes between pre- and post-tests for **A** the vertical group and **B** the horizontal group in horizontal jump performances (squat jump [SJ], countermovement jump [CMJ] and drop jump [DJ]), sprint performances (sprint time at 5 m, 10 m, 15 m and 30 m) and force–velocity profile parameters (including the maximal force [F_0], the maximal power [P_{max}], the maximal force ratio [RF_{max}] and the decrease rate in RF with increasing speed [DRF]). *ns* no significant changes in vertical group or horizontal group, *a* significant difference between relative changes assessed in VG and HG ($p < 0.05$)

Table 5 Performances in 30-m sprint and change of direction test before (Pre-test) and after (Post-test) the 8-week plyometric training for the vertical (VG) and horizontal (HG) groups

	Group	Pre-test	Post-test	Statistical effects	
5 m time (s)	VG	1.49 ± 0.09	1.39 ± 0.07[a]	*Group*time* $p = 0.024$ $\eta^2_p = 0.182$	$p = 0.001$ $d = 1.218$
	HG	1.53 ± 0.10	1.34 ± 0.09[a]		$p = 0.001$ $d = 1.927$
10 m time (s)	VG	2.30 ± 0.09[§]	2.17 ± 0.09[a]		$p = 0.001$ $d = 1.547$
	HG	2.31 ± 0.11	2.12 ± 0.10[a]		$p = 0.001$ $d = 1.806$
15 m time (s)	VG	3.00 ± 0.13	2.86 ± 0.12[a]		$p = 0.001$ $d = 1.284$
	HG	3.09 ± 0.27	2.81 ± 0.11[a]		$p = 0.001$ $d = 1.336$
30 m time (s)	VG	5.02 ± 0.22	4.78 ± 0.22[a]		$p = 0.001$ $d = 1.089$
	HG	5.03 ± 0.23	4.73 ± 0.18[a]		$p = 0.001$ $d = 1.491$
Change of direction test (s)	VG	5.72 ± 0.18	5.71 ± 0.18	*ns*	/
	HG	5.76 ± 0.22	5.73 ± 0.15		/

[a]significantly different from the pre-test, η^2p partial eta squared (from ANOVA main effect), *d* Cohen's d (from Tukey HSD post-hoc test), *ns* non-significant

$p = 0.001$, $d = 1.701$ | Fig. 2C) and RF_{max} (VG: + 7.2%, $p = 0.001$, $d = 1.297$ | HG: + 13.5%, $p = 0.001$, $d = 2.142$ | Fig. 2D). DRF was significantly improved in HG (+ 28.6%, $p = 0.003$, $d = 1.168$ | Fig. 2E). No significant change was found for V_0 neither in VG nor in HG ($p > 0.05$, Fig. 2B). A significant difference was found in relative change between VG and HG for P_{max} ($p = 0.028$, $d = 0.754$), DRF ($p = 0.037$, $d = 0.701$) and RF_{max} ($p = 0.022$, $d = 0.796$).

Discussion

The aim of this study was to compare the effects of 8-week horizontal and vertical plyometric training programs on explosive qualities in young soccer players. Both types of plyometric training, regardless of orientation, led to improvements in sprint and jump performances. However, relative gains in horizontal performances (*i.e.*, jumps, sprint times and FVP parameters) were significantly higher in the horizontal plyometric group than in the vertical one while improvements in vertical performances were similar between the two groups.

The jump performances (*i.e.*, vertical and horizontal) and sprint results evaluated in the young soccer players included in the present study fall within the range as those reported in previous studies involving young athletes (Keller et al. 2020; Ramirez-Campillo et al. 2015). The values of the FVP parameters reported in young soccer players of the present study are also comparable to those documented in earlier investigations (Fernandez-Galvan et al. 2021; Zhang et al. 2021). The observed improvements in vertical jumps (*e.g.*, SJ, DJ) and sprint performances after 8-weeks of plyometric training assessed are in accordance with findings from previous studies involving plyometric training durations ranging from 6 to 10 weeks (Spurrs et al. 2003; Fouré et al. 2009; Chelly et al. 2014; Moran et al. 2021).

Only a few studies have conducted comparisons between the two orientations of plyometric training (Moran et al. 2021). Previous research examining younger soccer players who underwent 6 week of vertical or horizontal plyometric training found trivial or small differences in vertical and horizontal jump and sprint performances (Ramirez-Campillo et al. 2015). In elite handball players, a horizontal DJ protocol was shown to be more effective than a vertical DJ protocol, as evidenced by improved horizontal performance in 10 m sprint time and change of direction test (Dello Iacono et al. 2017). In the present study, both trained groups exhibited improvements in vertical SJ, vertical CMJ, and both vertical and horizontal DJ performances. However, only the HG demonstrated enhancements in horizontal SJ performances and improvements in horizontal DJ were larger in HG than in VG. Furthermore, a significantly greater relative decrease in 5 m and 15 m sprint times was observed in HG. Consequently, horizontal-oriented plyometric training resulted in improved performances in horizontal tests (*i.e.*, sprint and horizontal jumps). However, no improvement in sprint times involving changes of direction was observed for either the VG or the HG. This lack of improvement may stem from the

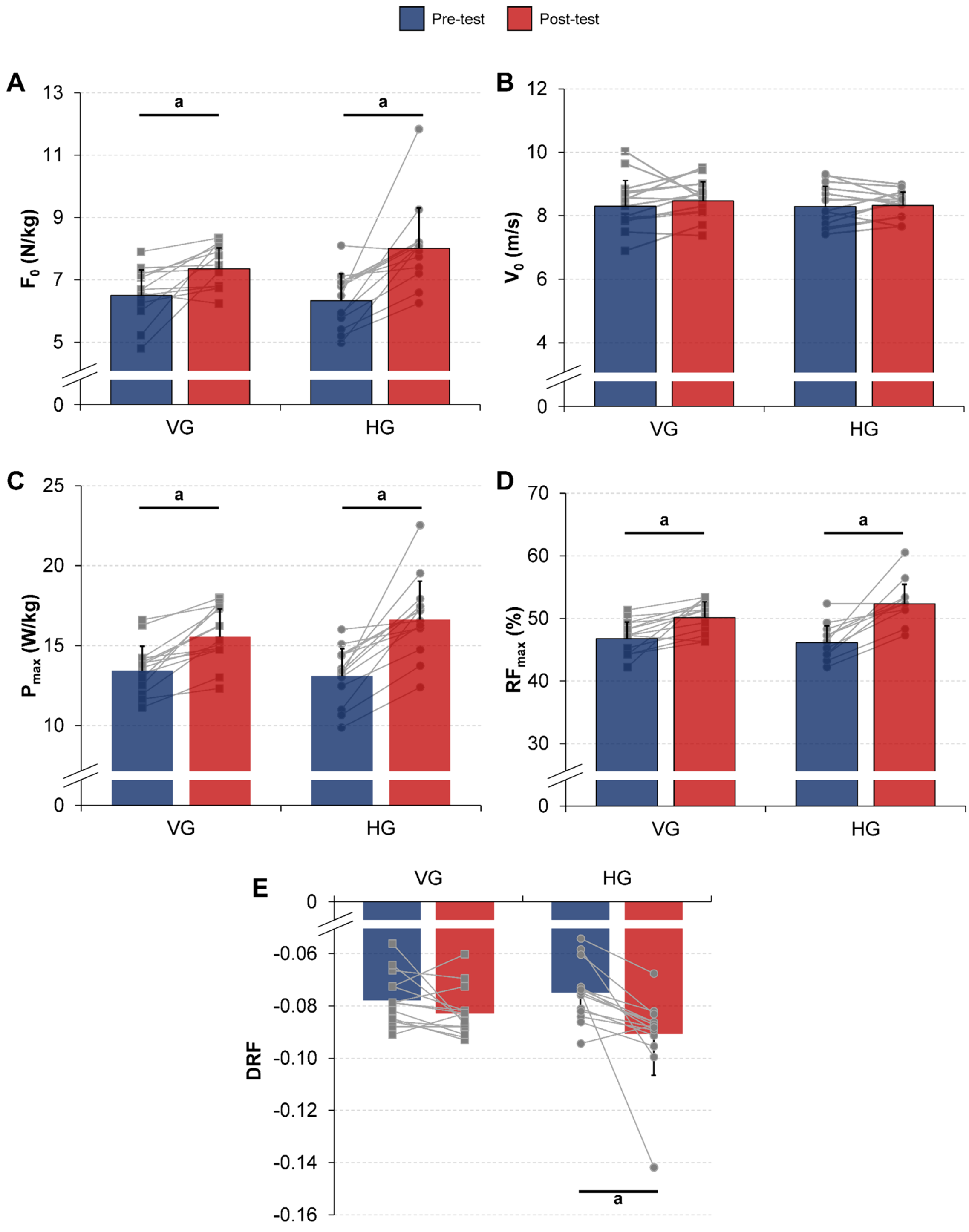

Fig. 2 Parameters of the force–velocity profile including **A** the theoretical maximal force (F_0), **B** the theoretical maximal velocity (V_0), **C** the theoretical maximal power (P_{max}), **D** the maximal force ratio (RF_{max}) and, **E** the decrease rate in RF with increasing speed (DRF) before (Pre-test) and after (Post-test) the plyometric training period for the trained vertical group (VG) and horizontal group (HG). [a]significantly different from Pre-test

comparatively low emphasis on lateral movements during horizontal training (*i.e.*, only 28% of the 2000 jumps) as well as the absence of lateral displacement in the vertical plyometric exercises.

Concerning FVP parameters assessed during a linear sprint, a single study has examined the short-term and combined effects of horizontal and vertical plyometric training protocols (Watkins et al. 2021). However, it remains challenging to isolate the potential impact of orientation from that study, given its comparatively low volume (*i.e.*, 40–60 ground contacts per session) and short duration (*i.e.*, 3 weeks) for each training intervention. In the present study, a significant effect of both vertical and horizontal training was observed for F_0, P_{max} and RF_{max}. Higher relative changes in RF_{max} and P_{max} were found for HG compared to VG. Moreover, a significant decrease in DRF was only observed in HG. Changes in functional performances (*i.e.*, jump and sprint) following plyometric training can be attributed to increased force capacities, primarily resulting from nervous adaptations such as a decreased inhibition of the myotatic reflex (Avela et al. 1999) an improved activation of agonist muscles and intermuscular coordination (Markovic and Mikulic 2010) as well as structural and mechanical adaptations (Spurrs et al. 2003; Fouré et al. 2009, 2010, 2011; Burgess et al. 2007; Wu et al. 2010) contributing to improve force production and transmission (Fouré et al. 2010; Wu et al. 2010; Burgess et al. 2007). The observed force gains may have contributed to improvements in FVP parameters, particularly in F_0, P_{max}, and RF_{max}. The improvements in horizontal jumps, linear sprint time, and DRF change during the 30 m sprint observed in the HG can be attributed, in this context of repeated measurements in the same individuals without changes in body weight after the training period, to a more efficient application of ground force (Samozino et al. 2022). A recent meta-analysis demonstrated that horizontal plyometric training yields superior performance on horizontally-oriented motor tasks compared to vertical plyometric training (Moran et al. 2021). The results obtained in the present study support the conclusions of the aforementioned analysis and highlight the significant influence of the horizontal plyometric training on the FVP determined during sprints. Regarding potential practical application, both horizontal and vertical plyometric training can be utilized to enhance both vertical and horizontal performances in jumps and sprints among young soccer player. However, it is noteworthy that the relative changes in horizontal jump and sprint performances, as well as force–velocity parameters, were more pronounced in the group undergoing horizontal plyometric training compared to the vertical plyometric training group.

It should be pointed out that comparing the training load between horizontally- and vertically-oriented plyometric exercises in the current study is challenging without assessing force and velocity during these exercises. Consequently, potential differences in motor task force and velocity characteristics may have significantly influence the results. Furthermore, data regarding muscular activity during both vertical and horizontal plyometric exercises, as well as testing tasks, would have been highly valuable for comparing coordination differences between the two orientations of the plyometric training (Jacobs and van Ingen Schenau 1992).

Lastly, it has been noted that the development of physical qualities is correlated with biological maturation in young soccer players (Mendez-Villanueva et al. 2011). Hence, the training-induced adaptations observed in the present study may have been more readily achieved in the population of young soccer players compared to a more general population.

Limitations

Regarding the methodological limitations related to the present study, the inclusion of FVP assessment during vertical jump could have been highly valuable in determining the potential significant and specific influence of vertical plyometric training on vertically-oriented motor task, despite no significant relative gains for the VG regarding vertical jump performances in comparison to the HG. Additionally, no electromyographic data collection during jumping and agility tests have been undertaken. This kind of measurements could provide insight into the muscular synergies involved in executing precise movement (Hug et al. 2010), as well as the impact of flexibility quality in motor coordination (Rodriguez Fernandez et al. 2016).

Perspective

Further studies are necessary to evaluate the potential specific effects of longer-duration horizontal and vertical training protocols, particularly regarding musculoskeletal structural adaptations. Additionally, the comparison of directions (*i.e.*, lateral and anterior) of horizontal plyometric exercises needs to be further investigated.

Acknowledgements The authors thank all the participants who participated to the present study.

Author contributions F.N. and A.F. contributed to the conception and the design of the study; F.N. and A.F. contributed to the literature review; F.N. contributed to the collection of the data; F.N. and A.F. contributed to the data analysis and interpretation; F.N. and A.F. contributed to the statistical analyses, F.N. and A.F. have written the manuscript and reviewed/edited a draft of the manuscript.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest, financial or otherwise.

Ethical approval The study was conducted in conformity with the last version of the Declaration of Helsinki and has been approved by the local ethics committee.

Consent to participate Informed consent was obtained from all individual participants included in the study.

References

Avela J, Kyrolainen H, Komi PV, Rama D (1999) Reduced reflex sensitivity persists several days after long-lasting stretch-shortening cycle exercise. J Appl Physiol (1985) 86(4):1292–1300

Balsalobre-Fernandez C, Glaister M, Lockey RA (2015) The validity and reliability of an iPhone app for measuring vertical jump performance. J Sports Sci 33(15):1574–1579. https://doi.org/10.1080/02640414.2014.996184

Barrera-Dominguez FJ, Almagro BJ, Saez de Villarreal E, Molina-Lopez J (2023) Effect of individualised strength and plyometric training on the physical performance of basketball players. Eur J Sport Sci. https://doi.org/10.1080/17461391.2023.2238690

Burgess KE, Connick MJ, Graham-Smith P, Pearson SJ (2007) Plyometric vs. isometric training influences on tendon properties and muscle output. J Strength Cond Res 21(3):986–989. https://doi.org/10.1519/R-20235.1

Cazorla G, Ezzeddine-Boussaidi LB, Maillot J, Morlier J (2008) Physical qualities carried out on swerve sprint in team sports. Sci Sports 23:19–21. https://doi.org/10.1016/j.scispo.2007.11.002

Chelly MS, Hermassi S, Aouadi R, Shephard RJ (2014) Effects of 8-week in-season plyometric training on upper and lower limb performance of elite adolescent handball players. J Strength Cond Res 28(5):1401–1410. https://doi.org/10.1519/JSC.0000000000000279

Cohen J (1969) statistical power analysis for the behavioral sciences. Academic Press, New-York

Dello Iacono A, Martone D, Milic M, Padulo J (2017) Vertical- vs. horizontal-oriented drop jump training: chronic effects on explosive performances of elite handball players. J Strength Cond Res 31(4):921–931. https://doi.org/10.1519/JSC.0000000000001555

Ettema G (2024) The force-velocity profiling concept for sprint running is a dead end. Int J Sports Physiol Perform 19(1):88–91. https://doi.org/10.1123/ijspp.2023-0110

Faude O, Koch T, Meyer T (2012) Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 30(7):625–631. https://doi.org/10.1080/02640414.2012.665940

Fernandez-Galvan LM, Boullosa D, Jimenez-Reyes P, Cuadrado-Penafiel V, Casado A (2021) Examination of the sprinting and jumping force-velocity profiles in young soccer players at different maturational stages. Int J Environ Res Public Health. https://doi.org/10.3390/ijerph18094646

Fouré A, Nordez A, Guette M, Cornu C (2009) Effects of plyometric training on passive stiffness of gastrocnemii and the musculo-articular complex of the ankle joint. Scand J Med Sci Sports 19(6):811–818. https://doi.org/10.1111/j.1600-0838.2008.00853.x

Fouré A, Nordez A, Cornu C (2010) Plyometric training effects on Achilles tendon stiffness and dissipative properties. J Appl Physiol 109(3):849–854. https://doi.org/10.1152/japplphysiol.01150.2009

Fouré A, Nordez A, McNair P, Cornu C (2011) Effects of plyometric training on both active and passive parts of the plantarflexors series elastic component stiffness of muscle-tendon complex. Eur J Appl Physiol 111(3):539–548. https://doi.org/10.1007/s00421-010-1667-4

Haynes T, Bishop C, Antrobus M, Brazier J (2019) The validity and reliability of the My Jump 2 app for measuring the reactive strength index and drop jump performance. J Sports Med Phys Fitness 59(2):253–258. https://doi.org/10.23736/S0022-4707.18.08195-1

Hug F, Turpin NA, Guevel A, Dorel S (2010) Is interindividual variability of EMG patterns in trained cyclists related to different muscle synergies? J Appl Physiol 108(6):1727–1736. https://doi.org/10.1152/japplphysiol.01305.2009

Jacobs R, van Ingen Schenau GJ (1992) Intermuscular coordination in a sprint push-off. J Biomech 25(9):953–965. https://doi.org/10.1016/0021-9290(92)90031-u

Keller S, Koob A, Corak D, von Schoning V, Born DP (2020) How to improve change-of-direction speed in junior team sport athletes-horizontal, vertical, maximal, or explosive strength training? J Strength Cond Res 34(2):473–482. https://doi.org/10.1519/JSC.0000000000002814

Loturco I, Pereira LA, Kobal R, Zanetti V, Kitamura K, Abad CC, Nakamura FY (2015) Transference effect of vertical and horizontal plyometrics on sprint performance of high-level U-20 soccer players. J Sports Sci 33(20):2182–2191. https://doi.org/10.1080/02640414.2015.1081394

Markovic G, Mikulic P (2010) Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. Sports Med 40(10):859–895. https://doi.org/10.2165/11318370-000000000-00000

Mendez-Villanueva A, Buchheit M, Simpson B, Peltola E, Bourdon P (2011) Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? J Strength Cond Res 25(9):2634–2638. https://doi.org/10.1519/JSC.0b013e318201c281

Moran J, Ramirez-Campillo R, Liew B, Chaabene H, Behm DG, Garcia-Hermoso A, Izquierdo M, Granacher U (2021) Effects of vertically and horizontally orientated plyometric training on physical performance: a meta-analytical comparison. Sports Med 51(1):65–79. https://doi.org/10.1007/s40279-020-01340-6

Morin JB, Samozino P (2016) interpreting power-force-velocity profiles for individualized and specific training. Int J Sports Physiol Perform 11(2):267–272. https://doi.org/10.1123/ijspp.2015-0638

Ramirez-Campillo R, Meylan C, Alvarez C, Henriquez-Olguin C, Martinez C, Canas-Jamett R, Andrade DC, Izquierdo M (2014) Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. J Strength Cond Res 28(5):1335–1342. https://doi.org/10.1519/JSC.0000000000000284

Ramirez-Campillo R, Gallardo F, Henriquez-Olguin C, Meylan CM, Martinez C, Alvarez C, Caniuqueo A, Cadore EL, Izquierdo M (2015) Effect of vertical, horizontal, and combined plyometric training on explosive, balance, and endurance performance of young soccer players. J Strength Cond Res 29(7):1784–1795. https://doi.org/10.1519/JSC.0000000000000827

Rodriguez Fernandez A, Sanchez J, Rodriguez Marroyo JA, Villa JG (2016) Effects of seven weeks of static hamstring stretching on flexibility and sprint performance in young soccer players according to their playing position. J Sports Med Phys Fitness 56(4):345–351

Romero-Franco N, Jimenez-Reyes P, Castano-Zambudio A, Capelo-Ramirez F, Rodriguez-Juan JJ, Gonzalez-Hernandez J, Toscano-Bendala FJ, Cuadrado-Penafiel V, Balsalobre-Fernandez C (2017) Sprint performance and mechanical outputs computed with an iPhone app: comparison with existing reference methods. Eur J Sport Sci 17(4):386–392. https://doi.org/10.1080/17461391.2016.1249031

Saez de Villarreal E, Requena B, Cronin JB (2012) The effects of plyometric training on sprint performance: a meta-analysis. J Strength Cond Res 26(2):575–584. https://doi.org/10.1519/JSC.0b013e318220fd03

Samozino P, Peyrot N, Edouard P, Nagahara R, Jimenez-Reyes P, Vanwanseele B, Morin JB (2022) Optimal mechanical force-velocity profile for sprint acceleration performance. Scand J Med Sci Sports 32(3):559–575. https://doi.org/10.1111/sms.14097

Spurrs RW, Murphy AJ, Watsford ML (2003) The effect of plyometric training on distance running performance. Eur J Appl Physiol 89(1):1–7. https://doi.org/10.1007/s00421-002-0741-y

Vigne G, Gaudino C, Rogowski I, Alloatti G, Hautier C (2010) Activity profile in elite Italian soccer team. Int J Sports Med 31(5):304–310. https://doi.org/10.1055/s-0030-1248320

von Lieres Und Wilkau HC, Bezodis NE, Morin JB, Irwin G, Simpson S, Bezodis IN, (2020) The importance of duration and magnitude of force application to sprint performance during the initial acceleration, transition and maximal velocity phases. J Sports Sci 38(20):2359–2366. https://doi.org/10.1080/02640414.2020.1785193

Watkins CM, Gill ND, Maunder E, Downes P, Young JD, McGuigan MR, Storey AG (2021) The effect of low-volume preseason plyometric training on force-velocity profiles in semiprofessional rugby union players. J Strength Cond Res 35(3):604–615. https://doi.org/10.1519/JSC.0000000000003917

Wilson JM, Flanagan EP (2008) The role of elastic energy in activities with high force and power requirements: a brief review. J Strength Cond Res 22(5):1705–1715. https://doi.org/10.1519/JSC.0b013e31817ae4a7

Wu YK, Lien YH, Lin KH, Shih TT, Wang TG, Wang HK (2010) Relationships between three potentiation effects of plyometric training and performance. Scand J Med Sci Sports 20(1):e80-86. https://doi.org/10.1111/j.1600-0838.2009.00908.x

Young WB (2006) Transfer of strength and power training to sports performance. Int J Sports Physiol Perform 1(2):74–83. https://doi.org/10.1123/ijspp.1.2.74

Zhang Q, Pommerell F, Owen A, Trama R, Martin C, Hautier CA (2021) Running patterns and force-velocity sprinting profiles in elite training young soccer players: a cross-sectional study. Eur J Sport Sci. https://doi.org/10.1080/17461391.2020.1866078