Sport Sciences for Health
https://doi.org/10.1007/s11332-025-01400-2

RESEARCH

Effects of a short-term plyometric training on cement and synthetic turf surfaces in young soccer players

Roberto Modena[1,2] · Francesca Nardello[2] · Federico Schena[1,2]

Received: 18 October 2024 / Accepted: 31 March 2025

Abstract

Purpose We investigated the effects of plyometric training on synthetic grass or concrete surfaces on the physical performance of young soccer players.

Methods The participants were blocked randomly assigned to a synthetic turf (SYN, $n = 9$), a concrete surface (CEM, $n = 10$) or a control group (CON, $n = 8$). Performance (vertical jump, sprint, and agility) and perceptual measures were performed before and after 4 weeks of plyometric training.

Results The within-group effect showed improvements in jump height for CEM, rate of force development during the countermovement jump for SYN, 20-m sprint for CON and CEM, and COD (Change Of Direction) time for all groups ($p < 0.05$). Significant between-group effects of the training surface were observed only for squat jump height and the ratio between the countermovement jump and squat jump height ($p < 0.05$).

Conclusion A short-term plyometric protocol performed on cement or synthetic turf surfaces induced similar jump and sprint performance effects, by not determining specific adaptations in young soccer players.

Keywords Youth · Football · Jumping · Agility

Introduction

High-to-maximal-intensity activities such as sprinting, changing direction, and jumping are critical determinants of soccer performance in both senior and young players [1, 2]. Studies have shown that high-level and elite youth players outperform their low-level counterparts in jump and sprint performances [3], suggesting the importance of developing these skills for career development. Youth players who excel in jumping and sprinting are more likely to compete at higher levels as they transition to an adult competition [4]. Consequently, enhancing jumping and sprinting abilities should be the primary focus of youth soccer training programs.

Plyometric training, characterized by a rapid transition between eccentric and concentric muscle contractions (stretch–shortening cycle, SSC), has been extensively studied over the past decade [5]. This form of training is widely supported for its effectiveness in improving sprint and jump performance [6–8] as well as the ability to change direction [9].

The SSC is crucial for various explosive activities in soccer, including acceleration, directional changes, and vertical/horizontal jumps [10, 11]. Research indicates that plyometric training can enhance performance in these areas with beneficial effects for soccer athletes [12, 13].

The type of surface used during plyometric training significantly influences SSC speed. By contrast, Ramirez-Campillo et al. [10] reported that only approximately 66% of studies on this topic provided detailed information about the training surface, and even fewer quantified surface hardness. This highlights a gap in the literature, emphasizing the need for further comparative studies of different training surfaces. Notably, greater improvements in countermovement jump (CMJ) performance were observed following plyometric training on grass than sand [14]. Similarly, another study found that gym mat training improved squat jump (SJ)

✉ Roberto Modena
roberto.modena@univr.it

[1] CeRiSM (Sport Mountain and Health Research Centre), University of Verona, Piazza Manifattura 1, 38068 Rovereto, TN, Italy

[2] Neurosciences, Biomedicine and Movement Sciences Department, University of Verona, Verona, Italy

Published online: 22 April 2025

performance, with even greater effects observed after training on a wooden floor [15]. Recently, Ramirez-Campillo, et al. [7] demonstrated significant improvements in explosive actions (e.g., CMJ, SJ, drop jump) among soccer players following plyometric training on various surfaces, including grass, dirt, sand, wood, gym mats, and tartan tracks, compared to grass alone. Currently, most of the studies on plyometric training are affected by certain methodological limitations, such as the absence of a control group and lack of detailed information, including surface type and training protocol descriptions [10]. However, two recent studies on a non-sportive young population showed the efficacy of plyometric exercise in improving explosive performance in comparison to general physical exercise. Marzouki et al. [16] showed that experimental groups (e.g., firm group and sand group) attained more significant improvements in all assessed variables (i.e., sprint, jumping and change of direction speed) if compared to the control group following 4 weeks of plyometric training. They stated that the training-induced fitness changes were not influenced by the type of surface and sex. Similar findings were confirmed in another research by the same authors [17]: they compared the same plyometric intervention performed on clay (i.e., firm surface) and dry (i.e., sand surface) terrains, demonstrating that both were more efficient in improving several explosive performance than the control group, independently by type of surface but by age and sex. On the other hand, other researchers supported the rationale that the type of surface used in plyometric training can significantly influence training outcomes, as softer surfaces may result in longer ground contact times and slower SSCs than harder surfaces [18]. For instance, while softer surfaces, such as synthetic turf, may induce different responses than harder surfaces, such as cement, some studies, as example that by Ramlan et al., have found no significant differences in jumping performance between grass and cement surfaces in volleyball athletes [19].

It remains unclear whether plyometric training on harder surfaces (e.g., cement) can lead to greater improvements in jump and sprint performance than training on softer surfaces (e.g., synthetic turf). This distinction is particularly relevant for coaches and athletes in team sports such as soccer, rugby, and football, who often train on natural grass or synthetic turf but may perform plyometric exercises on more rigid surfaces. The primary objective of this study was to compare the effects of plyometric training performed on synthetic turf and cement on the vertical jump and sprint performance in young soccer players. In addition, this study aimed to determine whether a short-term plyometric training regimen (4 weeks) can elicit adaptations in youth soccer players returning to training with the team after an individual low-intensity and volume activity period.

Based on previous findings, we hypothesized that a 4-week plyometric intervention would improve vertical jump performance in both plyometric training groups compared with the control group. Furthermore, we would expect higher improvement in the drop jump performance for the concrete surface compared with the synthetic group due to the more rigid characteristics of the first, as shown by the restitution coefficient of the surfaces used. This outcome could be due to the higher rigidity of the surface, which could better stimulate the SSC mechanism. Finally, we assumed that a short period of plyometric training (twice a week for 4 weeks) would not be sufficient to improve sprint performance, as shown in the meta-analysis of Ramirez-Campillo and colleagues [10]. It seems that a training period lasting less than 7 weeks seems to be not sufficient for impacting sprint performance.

Material and methods

Experimental approach to the study

A parallel, randomized control trial design was used, where subjects were allocated using blocked randomization (i.e., where the participants were first sorted by their role (blocks) and then randomly allocated to the three groups) to either a control group (CON, no intervention) or two intervention groups: CEM (plyometric training on cement) and SYN (plyometric training on synthetic turf).

Pre-intervention measurements were performed 1 week before the beginning of the training period, and post-intervention measurements were performed one week after the end of the training period. The period occurred between the end of the intervention and the tests were chosen as tapering strategy which may lead to a greater improvement of performance, as previously demonstrated [20].

Although the study was conducted during the in-season period (between March and May 2021), participants only completed individual training over the month before the study owing to COVID-19 restrictions. All participants completed two familiarization sessions before beginning the experimental procedure to minimize potential learning effects.

Since the absence of training load monitoring during the intervention period could be a bias for results interpretation, we tried to attenuate it as much as possible through three steps: i) balancing the groups by different player positions; ii) all the participants belonged to the same team; thus, they performed the same training sessions during the intervention period (with the exception of the technical instead of plyometric training for the CON group); iii) we collected the Rate of Perceived Exertion at the end of every plyometric session and compared it between the CEM and SYN conditions.

Participants

Twenty-seven young soccer players were recruited from a soccer team competing at the regional level. A sample size of 8 participants per group was estimated a priori based on the data of a similar study [7], to obtain a statistical power of 80% with $\alpha = 0.05$.

Therefore, soccer players were allocated by considering a balanced proportion of field positions, as follows: goalkeepers (CON: 1, CEM: 1, SYN: 1), defenders (2, 2, 2), midfielders (4, 5, 4), and forward (1, 2, 2). The randomization sequence was generated electronically (https://www.randomlists.com/team-generator) by a blinded researcher who had no relationship with the participants. The player characteristics are listed in Table 1.

All players had a history of ≥ 2 years of systematic soccer training, competitive match experience, and the absence of potential medical problems, including recent (previous 2 months) lower extremity injuries that could compromise participation.

The participants and their parents or guardians provided informed consent before the training/experimental sessions.

The ethical review board for studies involving human participants (CARP) of the Department of Neurosciences, Biomedicine and Movement Sciences of the University of Verona approved the study protocol (Prot. 2021-UNVRCLE-0188168).

Plyometric training program

The plyometric sessions were completed twice a week for 4 weeks during the first part of the team's training sessions, lasting 72 h. A standardized 15-min warm-up based on FIFA 11+ [21] was carried out before each plyometric and technical session. Both intervention groups (CEM and SYN) performed the same plyometric training program, previously proposed by Lloyd et al. [22] as reported in Table 2. The CEM performed plyometric drills on the cement surface. In contrast, SYN performed these tasks on a synthetic turf, where players usually train. The participants rested for 90 s and 3 min between repetitions and sets, respectively.

The training load of plyometric intervention was assessed by Rate of Perceived Exertion (RPE, CR-10 Borg Scale) [23] collected at the end of every plyometric session for both CEM and SYN groups.

Instead of a plyometric intervention, the CON group performed low-intensity technical drills (i.e., passing, dribbling, and kicking) on synthetic turf. The difference in surface hardness was verified by assessing the restitution coefficient [15]. This parameter was determined using a video camera sampling at 60 Hz (Xiaomi Redmi Note 9 Pro, Cina) and the free software Tracker (http://physlets.org). In our study, the restitution coefficient of a tennis ball was measured for two training surfaces, with values of 0.637 and 0.475 for the cement surface and synthetic turf, respectively. The floor used for the jumping tests exhibited a restitution coefficient of 0.671.

Evaluation procedures

The participants were asked to avoid drinking and eating two hours before the tests, and to refrain from participating in exercise activities the day before the test.

Players were evaluated over three days with 48 h of rest, due to both logistic and methodological reasons. To be precise, jump tests were conducted indoor in the Biomechanics laboratory (University of Verona) where a force platform was present, while sprint test was carried out outdoor on the same field where players usually train. Moreover, the time between sessions was chosen to avoid the presence of fatigue. On the first day, data on body mass, height, sitting height, weekly time spent practicing other sports activities, and years of soccer experience were collected (Table 1). On the second day, the jumping tests were conducted. On the last day, 20 m sprint time and

Table 1 Characteristics of participants

	CON ($n = 8$)	CEM ($n = 10$)	SYN ($n = 9$)	Group effect (p value)
Age (years)	15.9 ± 0.6	16.2 ± 0.5	15.5 ± 0.6	0.116
Body height (m)	1.75 ± 0.66	1.73 ± 0.87	1.76 ± 0.72	0.537
Body mass (kg)	67.0 ± 9.9	68.4 ± 9.1	65.1 ± 11.2	0.756
Body Mass Index (kg·m^{-2})	21.9 ± 2.9	21.9 ± 3.1	20.7 ± 2.2	0.311
Peak Height Velocity offset (years)	4.0 ± 0.7	3.7 ± 0.8	3.6 ± 1.3	0.806
Extra soccer training (hours)	3.0 ± 2.4	2.1 ± 2.0	2.1 ± 1.4	0.592

Data are mean ± SD

CON control group, *CEM* concrete surface group, *SYN* grass surface group

Table 2 Plyometric training program outline, from Lyoid et al. (2012)

Exercise	Week 1		Week 2		Week 3		Week 4	
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8
Squat jump	2 × 6							
Countermovement jump	2 × 6	2 × 8						
Pogo hopping	2 × 8	2 × 8	3 × 8	2 × 10	2 × 10	4 × 8	4 × 10	4 × 10
Standing long jump	2 × 8	4 × 4	2 × 3					
Lateral hops	2 × 8	4 × 8	4 × 8					
Hop scotch			3 × 4					
Bilateral "power" hops			4 × 3					
Ankle jumps				3 × 5	3 × 5			
"Power" skipping				3 × 8	3 × 8	3 × 8		
Unilateral pogo hops				2 × 10	2 × 10	2 × 8	2 × 10	2 × 10
Max rebound hops				3 × 5	3 × 5	4 × 5	3 × 5	3 × 5
Drop jumps						3 × 5	4 × 4	4 × 4
Hurdle "power" hops							3 × 5	3 × 5
Total foot contacts	72	80	86	94	94	102	106	106
Mean ± SD								
RPE SYN [AU]	2.15 ± 1.61	2.25 ± 1.31	1.81 ± 1.13	1.61 ± 0.89	1.36 ± 0.88	1.31 ± 0.95	1.36 ± 1.11	1.15 ± 0.86
RPE CEM [AU]	2.18 ± 1.23	2.62 ± 0.64	1.72 ± 0.90	1.66 ± 0.93	1.26 ± 0.80	1.30 ± 0.71	1.16 ± 0.64	1.25 ± 0.53

For every plyometric session the RPE scores have been reported for both CEM and SYN groups

RPE rate of perceived exertion, *CEM* concrete surface group, *SYN* grass surface group

change of direction test (COD time) time were evaluated in a synthetic soccer field. A 3-min passive rest was allowed between each trial. The same researcher gave strong verbal encouragement during every trial, to maximize their effort during the tests.

Twelve minutes of general (running exercise) and specific (walking lunges, vertical jump, lateral jumps) warm-up were performed outdoors before each testing session [21]. Immediately after the warm-up and before any experimental evaluation, each participant reported perceived pain in their lower limbs on the VAS 100 scale [24].

Anthropometric characteristics and maturation

Body and sitting heights were measured using a stadiometer (Gima, Italy) and body mass was measured using an electronic scale (Rowenta, Italy). Each measurement was performed three times, and the average value was used for the analysis. The maturation status of the participants was estimated as the offset from the Peak Height Velocity (PHV-offset) [25].

Jumping tests

Participants performed at least five trials of the CMJ, squat jump (SJ), and drop jump from 40 cm of height (DJ), keeping their hands on the iliac crest to minimize the influence of the upper limbs on jump performance. All jumps were performed randomly on a force platform (Model AMTI, USA; sampling rate, 1000 Hz). Furthermore, during the DJ, players were instructed to minimize ground contact time, and only trials with contact time < 250 ms were considered [15].

The takeoff and landing phases were standardized to the same spot, and the players were required to perform full knee and ankle extensions during the flight phase. All tests were checked visually and those that did not meet these criteria were discarded. We discarded two trials maximum for each subject, ensuring at least three trials for every jump and participant. The average values for each jump type were used for further analysis.

Jump height was estimated from the flight time and calculated as the time between takeoff and subsequent landing [26]. The eccentric utilization ratio was calculated as the CMJ/SJ ratio to provide information on the slow SSC performance [27]. The vertical force–time data were filtered using a 6 th-order high-pass filter with a cutoff frequency of 200 Hz. For both the CMJ and SJ, the force peak was calculated as the maximum force achieved over the force–time curve during the jump. In contrast, the time to the peak force to calculate the rate of force (RFD) was taken as the time from the start of the jump until the peak was reached [28]. For DJ, the Reactive Strength Index (RSI) was determined as the ratio of the flight to contact times [29]. Jump data analysis was performed using MATLAB (MathWorks, Natick, MA, USA).

Sprint performance

The 20 m sprint time was recorded using 2 telemetric photocell gates (Witty, Microgate, Bolzano, Italy) placed at a 20 m distance between. The players performed sprints starting from a still-standing position 0.5 m before the starting line. The COD test, as previously described [30], was performed using the same timing system and procedures as those used for the 20 m sprint.

Three trials of each test with full recovery (3 min) were completed. The average of the three trials was considered for further analysis.

Statistical analysis

All results are expressed as mean ± SD. The normal distribution of the data was tested using the Kolmogorov–Smirnov test, and the homogeneity assumption was not violated.

All measured parameters calculated from the jump and sprint tests were considered dependent variables, while the three conditions (CON, CEM, and SYN) were analyzed as independent factors. Analysis of covariance (ANCOVA) was used to compare the post-intervention values among the three groups with the pre-intervention values as a covariate. Post-hoc tests with Bonferroni-adjusted α values were performed to identify statistically significant differences. One-way ANOVA was used to assess anthropometric characteristics and maturation status to examine any pre-intervention group differences. For each group, a non-parametric Kruskal–Wallis test was performed to investigate the effect of time on VAS values to determine the players' recovery status before the evaluation sessions. Moreover, the same statistical test was used to verify the effect of surface on RPE during the eight plyometric sessions.

Statistical analyses were performed using SPSS ver. 22.0 (IBM, Chicago, IL, USA), with significance set at $p < 0.05$.

Results

Table 3 shows pre- and post-intervention data and reports the *p*-values of within- and between-group analysis.

At baseline, no significant differences were observed among the groups in anthropometric parameters, PHV-offset, or time spent on extra soccer activities (Table 1).

Moreover, no significant differences were observed in the VAS scores between the pre- and post-intervention sessions ($p > 0.05$). Before the strength sessions, VAS values were 1.7 ± 1.7, 4.0 ± 6.2 and 9.1 ± 11.8 at pre-intervention and 0.9 ± 1.4, 2.5 ± 3.2 and 3.1 ± 2.8 at post-intervention for CON, CEM and SYN respectively. Similarly, before the speed sessions, VAS values were 2.2 ± 2.5, 3.8 ± 6.2, and 4.7 ± 6.3 at pre-intervention and 0.9 ± 0.8, 1.9 ± 2.1 and 3.4 ± 3.7 at post-intervention for CON, CEM and SYN respectively. RPE showed no differences between CEM and SYN over the plyometric intervention (Table 2).

Jumping tests

Within-group analysis revealed that the CEM group had improved CMJ height (+ 2.18 [0.334.04] cm, d = 0.81, $p =$ 0.026), SJ height (+ 1.62 [0.013.23] cm, d = 0.72, $p = 0.049$), and DJ height (+ 2.87 [0.095.64] cm, d = 0.74, $p = 0.044$) after 4 weeks of plyometric training. Moreover, the SYN group showed increased RFD during the countermovement jump (+ 1452.7 [581.02324.4] N· s^{-1}, d = 1.39, $p = 0.006$). Between-group analysis showed evidence of a training effect on SJ height ($p = 0.002$) and CMJ/SJ height ratio ($p =$ 0.005); in particular, SJ height was improved in the CEM ($p = 0.004$) and SYN ($p = 0.004$) groups compared with the CON group. No significant differences have been observed in the other parameters (Fig. 1).

Sprinting tests

The within-group analysis showed improvement in the 20 m sprint time in the CON (−0.10 [−0.01 to −0.18] s, d = 1.21, $p = 0.031$) and CEM (−0.12 [−0.06 to −0.18] s, d = 1.45, $p = 0.001$) group post-intervention. Moreover, COD time at post-intervention decreased in CON (−0.61 [−0.42 to −0.79] s, d = 3.47, $p < 0.001$), CEM (−0.87 [−0.66 to −1.08] s, d = 2.93, $p = 0.001$) and SYN (−0.69 [−0.48 to −0.90] s, d = 2.55, $p < 0.001$) group. ANCOVA analysis showed no significant differences between the groups in the 20 m sprint and COD times.

Discussion

This study aimed to investigate the effect on the jump and sprint performance of a short-term plyometric intervention performed twice a week on a cement surface or a synthetic turf in young soccer players. Evidence of the time effect was shown in height jumps in the CEM group and in RFD during countermovement jumps in the SYN group. Moreover, time affected the 20-m sprint and COD performance in both the CON and CEM groups, and only the COD time in the SYN group was affected. However, evidence of differences among groups emerged only in the squat jump height (both CEM and SYN were higher than CON) and the CMJ/SJ ratio (SYN improved more than CON).

As discussed in the introduction, a relevant part of the literature on plyometric training may be biased by missing information and methodological limits. Several studies have reported improvements in jump and sprint performance after

Table 3 Outcome measures (Mean ± SD) for each group before (pre) and after (post) the training period

	CON (n = 8)		CEM (n = 10)		SYN (n = 9)		Within-group effect (T test p value)			Between-group effect (ANCOVA p-value)
	Pre	Post	Pre	Post	Pre	Post	CON	CEM	SYN	
Countermovement jump										
Height (cm)	33.1 ± 6.2	33.2 ± 5.8	**33.0 ± 4.6**	**35.1 ± 5.2**	31.5 ± 4.9	32.7 ± 4.7	0.948	*0.026*	0.152	0.228
RFD ($N \cdot s^{-1}$)	9560.1 ± 3097.3	9145.6 ± 2549.2	8676.0 ± 2506.8	9344.1 ± 2711.3	**6741.9 ± 2316.7**	**8558.3 ± 2577.3**	0.168	0.455	*0.013*	0.485
Peak force (N)	1735.1 ± 172.2	1657.7 ± 215.4	1799.4 ± 343.3	1802.3 ± 342.9	1565.2 ± 316.6	1610.2 ± 344.0	0.142	0.968	0.062	0.413
Squat jump										
Height (cm)	31.3 ± 5.3	29.2 ± 4.2	**32.2 ± 4.1**	**33.9 ± 4.1**	31.1 ± 5.0	33.2 ± 4.3	0.083	*0.049*	0.051	*0.002*
RFD ($N \cdot s^{-1}$)	5807.8 ± 2187.7	6263.6 ± 1541.1	7267.8 ± 3238.4	7341.0 ± 3346.6	5512.2 ± 2099.0	6651.6 ± 1197.5	0.259	0.243	0.316	0.649
Peak force (N)	1517.1 ± 138.3	1542.7 ± 98.7	1644.3 ± 303.7	1669.3 ± 317.3	1452.0 ± 294.8	1554.8 ± 350.3	0.139	0.731	0.095	0.246
CMJ/SJ height ratio	1.06 ± 0.10	1.14 ± 0.13	1.02 ± 0.09	1.04 ± 0.06	1.01 ± 0.05	0.98 ± 0.05	0.216	0.755	0.262	*0.005*
Drop jump										
Height (cm)	29.5 ± 5.6	31.9 ± 5.3	**28.5 ± 4.5**	**30.6 ± 5.5**	29.7 ± 5.4	31.5 ± 5.3	0.485	*0.044*	0.292	0.950
RSI ($m \cdot s^{-1}$)	1.19 ± 0.30	1.36 ± 0.43	1.22 ± 0.28	1.38 ± 0.42	1.20 ± 0.24	1.16 ± 0.20	0.787	0.466	0.922	0.235
Speed										
20 m sprint time (s)	**3.37 ± 0.15**	**3.26 ± 0.15**	**3.30 ± 0.15**	**3.19 ± 0.17**	3.28 ± 0.22	3.21 ± 0.13	*0.031*	*0.001*	0.150	0.527
COD time (s)	**8.06 ± 0.45**	**7.34 ± 0.54**	**7.98 ± 0.28**	**7.11 ± 0.34**	**8.01 ± 0.39**	**7.32 ± 0.40**	*< 0.001*	*< 0.001*	*< 0.001*	0.119

CON control group, *CEM* concrete surface group, *SYN* grass surface group, *CMJ* countermovement jump, *SJ* squat jump, *RFD* rate of force development, *RSI* reactive strength index, *COD* change of direction. Values in bold represent significant changes.

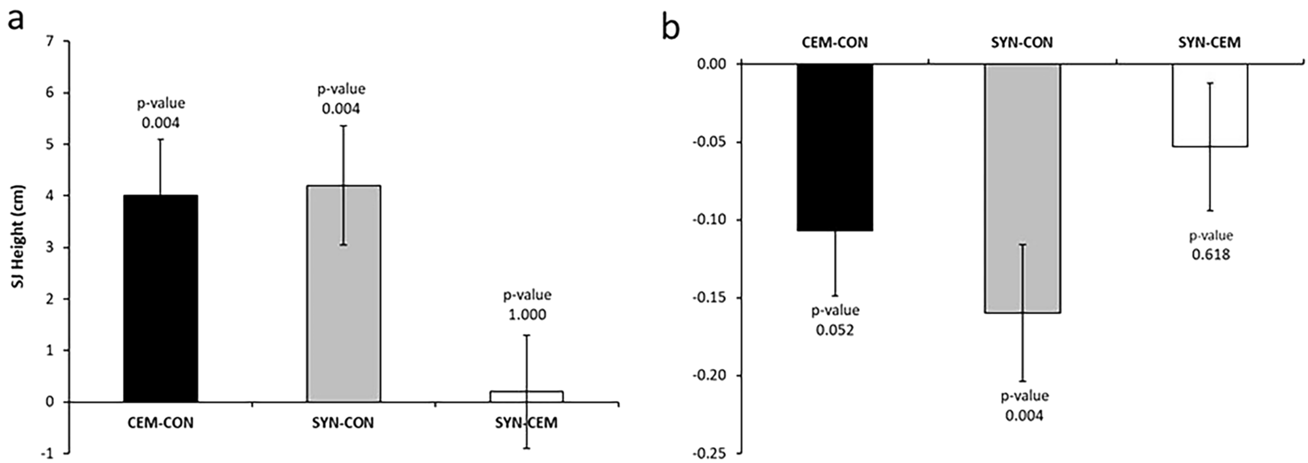

Fig. 1 Mean differences of pairwise comparisons: Squat Jump (SJ) height (panel a) and the ratio between Counter Movement Jump and Squat Jump (CMJ/SJ) height (panel b). Data are reported as mean and error standard; the p value has been reported, as well. CON, control group; CEM, concrete surface group; SYN, grass surface group

a plyometric training period without a control group (no intervention) or by performing only a within-group analysis [7, 31].

Our main aim was to verify the effects of the surface type used during the training. Moreover, the presence of a control group allowed us to evaluate the efficacy of a short plyometric training period after activity suspension due to COVID-19 restrictions, but it may be useful also after an off-season period or as a part of a return-to-play protocol.

In our study, the lack of an intervention effect, regardless of the type of surface for many parameters assessed, may be caused by the limited extension of the training period, maturity status of the players, and inactivity period that the players had to be observed before the study. Studies on high-level athletes have highlighted that a training period shorter than 7 weeks might cause difficulty in improving vertical jump and sprint performance [32]. Literature shows only a few data on young soccer players [7]. The young population exhibits a similar pattern: after a plyometric training period, it has been appreciated a small-to-moderate impact on jump and sprint performance in relation to several neural and muscular adaptations which provide, such as improvement in intra-muscular coordination and capacity in storing and reusing elastic energy during a fast movement [33].

Regarding the jump performance, some changes between pre- and post-intervention in both CEM and SYN were observed for several parameters (e.g., CMJ height and RFD and SJ height). However, between-group analysis showed a difference among interventions only in squat jump height, which seemed to improve after 4 weeks of plyometric training in both CEM and SYN compared to CON. This could be explained by the fact that an intervention of only eight sessions would be able to improve vertical oriented performance. The reviews of Ramirez-Campillo et al. [10] and Kons et al. [31] supported these results, showing that plyometric training interventions longer than 7 weeks are necessary to enhance horizontal-oriented outcomes such as sprint time.

Furthermore, the high training load represented by the plyometric program after an unusual period of inactivity was shown to likely negatively affect these positive adaptations; particularly in this context, an optimal management of the training load might be determinant [34].

Plyometric training can be performed on both firm and soft surfaces. In the former case, an increase in the elastic energy stored (owing to the high-stretch loads) was demonstrated in the pre-contraction activation state and a more significant stretch reflex [11]. On the other hand, softer surfaces seem to reduce stress on the musculoskeletal system and hence reduce the risk of injuries with substantially less muscle soreness [35].

The surface stiffness may influence the performance in different ways depending on the jump type. The performance of CMJ and DJ is enforced by the effects of pre-stretch gain [36], whereas a minimal pre-stretch phase is present during SJ, confirming that it is a movement characterized by strength and power provided concentrically and without the contribution of energy stored during the previous action [37].

Although there was no evidence of a difference between surfaces, countermovement and drop jump height increased in our study after the intervention (+ 6.4% and 10.5%) carried out on the cement. Simultaneously, they remained unchanged in the SYN and CON groups. This finding supports the hypothesis that plyometric training on a more rigid surface can positively affect the SSC. However, the short training period may have hidden potential differences between the surface types, which is in agreement with previous studies [6, 31, 33]. Moreover, both intervention groups showed improvement in squat jump height compared to the CON group, without differences between surfaces, in agreement with data reported in other sports such as basketball [6], hockey [38], cricket [39] and volleyball [19].

Also, the recent works of Marzouki and colleagues [16, 17] supported our findings in improvement on squat jump height without differences between surfaces. On the other hand, the positive effect on the other outcomes demonstrated by Marzouki et al. may be influenced by the fact they involved untrained younger schoolchildren. Moreover, in a short-period training, the specificity of the task may play a relevant role: the first adaptations might be mainly coordinative, mirroring the training task.

This study had some limitations. Although the sample size estimation supported that the number of participants we recruited was sufficient, the current study focused on a group of young soccer players who belonged to the same team and did not allow us to generalize the final results. Moreover, our findings may have been affected by the absence of a tapering period after the training period [40].

Conclusion

This study aimed to verify the role of surface hardness in a plyometric training program in order to overcome the limitations of previous studies. Although we found some positive effects of plyometric training on the squat jump and the ratio between countermovement and squat jump, certified by within-group analysis, the surface type (cement and synthetic turf in our case) did not seem to influence the training adaptations.

Our findings suggest that a short-term (4-week) training program carried out by post-PHV youth soccer players on a hard surface results in similar gains compared to a softer surface. Therefore, academy coaches may use different surfaces during plyometric drills to provide players with various stimuli and obtain similar adaptations in neuromuscular performance.

Acknowledgements We are grateful to the club and soccer players who participated and allowed us to complete the study. We would also like to thank Marco Verinelli and Nicola Giuliani for their valuable support in the data collection.

Author contributions R. M. and F. N. contributed to the study conception and design. Data collection and analysis were performed by F. N. and R. M. All authors contributed in equal way manuscript writing. All authors read and approved the final manuscript.

Funding Open access funding provided by Università degli Studi di Verona within the CRUI-CARE Agreement. The authors have not received any funding for this project.

Data availability Data is freely available. A request can be sent to the corresponding author's email.

Declarations

Conflict of interest The authors declare no competing interests.

Informed consent and Ethical approval The participants and their parents or guardians provided informed consent before the training/experimental sessions. The ethical review board for studies involving human participants (CARP) of the Department of Neuroscience, Biomedicine and Movement Science of the University of Verona approved the study protocol (Prot. 2021-UNVRCLE-0188168).

References

1. Castagna C, D'Ottavio S, Abt G (2003) Activity profile of young soccer players during actual match play. J Strength Cond Res 17(4):775–780
2. Faude O, Koch T, Meyer T (2012) Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 30:625–631. https://doi.org/10.1080/02640414.2012.665940
3. Vaeyens R, Malina RM, Janssens M et al (2006) A multidisciplinary selection model for youth soccer: the Ghent youth soccer project. Br J Sports Med. https://doi.org/10.1136/bjsm.2006.029652
4. le Gall F, Carling C, Williams M, Reilly T (2010) Anthropometric and fitness characteristics of international, professional and amateur male graduate soccer players from an elite youth academy. J Sci Med Sport. https://doi.org/10.1016/j.jsams.2008.07.004
5. Komi PV (2000) Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. J Biomech. https://doi.org/10.1016/s0021-9290(00)00064-6
6. Ozen G, Atar O, Koc H (2020) The effects of a 6-week plyometric training programme on sand versus wooden parquet surfaces on the physical performance parameters of well-trained young basketball players. Montenegrin J Sports Sci Med. https://doi.org/10.26773/mjssm.200304
7. Ramirez-Campillo R, Álvarez C, García-Pinillos F et al (2020) Effects of combined surfaces vs. single-surface plyometric training on soccer players' physical fitness. J Strength Cond Res 34:2644–2653. https://doi.org/10.1519/JSC.0000000000002929
8. Ramirez-Campillo R, Alvarez C, Gentil P et al (2020) Sequencing effects of plyometric training applied before or after regular soccer training on measures of physical fitness in young players. J Strength Cond Res. https://doi.org/10.1519/JSC.0000000000002525

9. Thomas K, French D, Hayes PR (2009) The effect of two plyometric training techniques on muscular power and agility in youth soccer players. J Strength Cond Res. https://doi.org/10.1519/JSC.0b013e318183a01a
10. Ramirez-Campillo R, Castillo D, Raya-González J et al (2020) Effects of plyometric jump training on jump and sprint performance in young male soccer players: a systematic review and meta-analysis. Sports Med 50:2125–2143
11. Bobbert MF (1990) Drop jumping as a training method for jumping ability. Sports Med 9:7–22
12. Bedoya AA, Miltenberger MR, Lopez RM (2015) Plyometric training effects on athletic performance in youth soccer athletes: a systematic review. J Strength Cond Res 29:2351–2360
13. van de Hoef PA, Brauers JJ, van Smeden M et al (2020) the effects of lower-extremity plyometric training on soccer-specific outcomes in adult male soccer players: a systematic review and meta-analysis. Int J Sports Physiol Perform 15:3–17. https://doi.org/10.1123/ijspp.2019-0565
14. Impellizzeri FM, Rampinini E, Castagna C et al (2008) Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. Br J Sports Med. https://doi.org/10.1136/bjsm.2007.038497
15. RamiRez-Campillo R, Andrade DC, Izquierdo M (2013) Effects of plyometric training volume and training surface on explosive strength. J Strength Cond Res 27:2714–2722. https://doi.org/10.1519/JSC.0b013e318280c9e9
16. Marzouki H, Dridi R, Ouergui I et al (2022) Effects of surface-type plyometric training on physical fitness in schoolchildren of both sexes: a randomized controlled intervention. Biology (Basel). https://doi.org/10.3390/biology11071035
17. Marzouki H, Ouergui I, Dridi R et al (2022) Effects of four weeks of plyometric training performed in different training surfaces on physical performances in school children: age and sex comparisons. Children. https://doi.org/10.3390/children9121914
18. Lesinski M, Prieske O, Beurskens R et al (2018) Effects of drop-height and surface instability on jump performance and knee kinematics. Int J Sports Med. https://doi.org/10.1055/s-0043-117610
19. Ramlan MH, Pitil PP, Wahed WJE (2018) Effects of plyometric training on grass surface and concrete surface on jumping performance among volleyball athletes. Malays J Mov Health Exerc. https://doi.org/10.15282/mohe.v7i2.236
20. Hermassi S, Ghaith A, Schwesig R et al (2019) Effects of short-term resistance training and tapering on maximal strength, peak power, throwing ball velocity, and sprint performance in handball players. PLoS ONE. https://doi.org/10.1371/journal.pone.0214827
21. Bizzini M, Impellizzeri FM, Dvorak J et al (2013) Physiological and performance responses to the "FIFA 11+" (part 1): Is it an appropriate warm-up? J Sports Sci 31:1481–1490. https://doi.org/10.1080/02640414.2013.802922
22. Lloyd RS, Oliver JL, Hughes MG, Williams CA (2012) The effects of 4-weeks of plyometric training on reactive strength index and leg stiffness in male youths. J Strength Cond Res. https://doi.org/10.1519/JSC.0b013e318242d2ec
23. Borg G (1998) Borg's Perceived Exertion And Pain Scales. Human Kinetics, Champaign
24. Nahler G (2009) visual analogue scale (VAS). In: Dictionary of Pharmaceutical Medicine
25. Mirwald RL, Baxter-Jones ADG, Bailey DA, Beunen GP (2002) An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc 34:689–694. https://doi.org/10.1097/00005768-200204000-00020
26. Bosco C, Luhtanen P, Komi PV (1983) A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol. https://doi.org/10.1007/BF00422166
27. McGuigan MR, Doyle TLA, Newton M et al (2006) Eccentric utilization ratio: Effect of sport and phase of training. J Strength Cond Res. https://doi.org/10.1519/R-19165.1
28. Maffiuletti NA, Aagaard P, Blazevich AJ et al (2016) Rate of force development: physiological and methodological considerations. Eur J Appl Physiol. https://doi.org/10.1007/s00421-016-3346-6
29. Lloyd RS, Oliver JL, Hughes MG, Williams CA (2009) Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. J Sports Sci. https://doi.org/10.1080/02640410903311572
30. Ford KR, Manson NA, Evans BJ et al (2006) Comparison of in-shoe foot loading patterns on natural grass and synthetic turf. J Sci Med Sport. https://doi.org/10.1016/j.jsams.2006.03.019
31. Kons RL, Orssatto LBR, Ache-Dias J et al (2023) Effects of plyometric training on physical performance: an umbrella review. Sports Med Open. https://doi.org/10.1186/s40798-022-00550-8
32. Slimani M, Chamari K, Miarka B et al (2016) Effects of plyometric training on physical fitness in team sport athletes: a systematic review. j Hum Kinet 53:231–247. https://doi.org/10.1515/hukin-2016-0026
33. Ramirez-Campillo R, Sortwell A, Moran J et al (2023) Plyometric-jump training effects on physical fitness and sport-specific performance according to maturity: a systematic review with meta-analysis. Sports Med Open. https://doi.org/10.1186/s40798-023-00568-6
34. Perroni F, Fittipaldi S, Falcioni L et al (2019) Effect of pre-season training phase on anthropometric, hormonal and fitness parameters in young soccer players. PLoS ONE. https://doi.org/10.1371/journal.pone.0225471
35. Markovic G, Mikulic P (2010) Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. Sports Med. https://doi.org/10.2165/11318370-000000000-00000
36. Kubo K, Kawakami Y, Fukunaga T (1999) Influence of elastic properties of tendon structures on jump performance in humans. J Appl Physiol. https://doi.org/10.1152/jappl.1999.87.6.2090
37. Hasson CJ, Dugan EL, Doyle TLA et al (2004) Neuromechanical strategies employed to increase jump height during the initiation of the squat jump. J Electromyogr Kinesiol. https://doi.org/10.1016/j.jelekin.2003.12.004
38. Amrinder S, Sakshi G, Singh SJ (2014) Effect of plyometric training on sand versus grass on muscle soreness and selected sportspecific performance variables in hockey players. J Hum Sport Exerc. https://doi.org/10.4100/jhse.2014.91.07
39. Khan MH, Ali K (2013) The effects of grass and clay plyometric training on jumping, sprinting and agility in collegiate cricketers. Int J Biomed Adv Res. https://doi.org/10.7439/ijbar.v4i12.575
40. Mujika I, Padilla S (2003) Scientific bases for precompetition tapering strategies. Med Sci Sports Exerc. https://doi.org/10.1249/01.MSS.0000074448.73931.11