Journal of Exercise Science & Fitness 19 (2021) 81–90

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Sprint and jump performances in highly trained young soccer players of different chronological age: Effects of linear VS. CHANGE–OF–DIRECTION sprint training

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ARTICLE INFO

Article history:
Received 28 May 2020
Received in revised form
10 October 2020
Accepted 11 October 2020
Available online 13 November 2020

Keywords:
Football
Repeated sprint
Performance
Speed

ABSTRACT

Objective: The aim of this study was to examine the effects of two different sprint-training regimes on sprint and jump performances according to age in elite young male soccer players over the course of one soccer season.

Methods: Players were randomly assigned to two training groups. Group 1 performed systematic change-of-direction sprints (CODST, U19 [n = 9], U17 [n = 9], U15 [n = 10]) while group 2 conducted systematic linear sprints (LST, U19 [n = 9], U17 [n = 9], U15 [n = 9]). Training volumes were similar between groups (40 sprints per week x 30 weeks = 1200 sprints per season). Pre and post training, all players performed tests for the assessment of linear and slalom sprint speed (5-m and 10-m), countermovement jump, and maximal aerobic speed performance.

Results: For all physical fitness measures, the baseline-adjusted means data (ANCOVA) across the age groups showed no significant differences between LST and CODST at post ($0.061 < p < 0.995$; $0.0017 < d < 1.01$). The analyses of baseline-adjusted means for all physical fitness measures for U15, U17, and U19 (LST vs. CODST) revealed no significant differences between LST and CODST for U15 ($0.213 < p < 0.917$; $0.001 < d < 0.087$), U17 ($0.132 < p < 0.976$; $0.001 < d < 0.310$), and U19 ($0.300 < p < 0.999$; $0.001 < d < 0.049$) at post.

Conclusions: The results from this study showed that both, LST and CODST induced significant changes in the sprint, lower limbs power, and aerobic performances in young elite soccer players. Since no significant differences were observed between LST and CODST, the observed changes are most likely due to training and/or maturation. Therefore, more research is needed to elucidate whether CODST, LST or a combination of both is beneficial for youth soccer athletes' performance development.

Introduction

It has previously been reported that soccer is the most popular sport in the world, especially among children and adolescents.[1–3] The physical demands in soccer and other team-sports are characterized by stochastic, acyclical and intermittent movement bouts, which are highly variable and unpredictable.[4] More specifically,

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https://doi.org/10.1016/j.jesf.2020.10.003

soccer-specific demands comprise intermittent high-intensity actions that involve various types of linear accelerations interspersed with rapid changes-of-directions (CoD), sudden starts, stops, jumps, and kicks.[5]

Several studies reported that more than 80% of physical activities during a match are spent at low-to-moderate intensities and the remaining 10–20% are classified as high-intensity activities.[6,7] Drust et al. (2000)[8] documented a mean number of 19 sprints during soccer matches in FA Premier League soccer. This corresponds to one sprint every 4–5 min. Strudwick et al. (2002)[9] observed that movement activity during a match changes every 3.5 s. More specifically, a bout of high-intensity activity occurs every 60 s, and a maximal effort every 4 min.[10] Similarly, Mohr et al. (2003)[11] examined activities during a soccer match in professional soccer players and noted that 19.5% of the match time, players were in a standing position, 41.8% involved walking, 16.7% involved jogging (>12 km/h), 16.8% running (12–20 km/h), 1.4% sprinting (>25 km/h), and 3.7% included other activities. During the most intense periods of a soccer game, players have to perform repeated high-intensity efforts and/or sprints.[12] Accordingly, the ability to repeat high-intensity efforts is an important quality for players' match performance.[13] As a consequence, CoD and repeated maximal linear sprint performances constitute key physical qualities in soccer, irrespective of age, sex, and expertise level.[2,3]

According to several authors, the ability to perform high-intensity sprints should be developed from an early age on in youth athletes.[14,15] Of note, genetic predisposition is a major factor that impacts on maximal sprint performances.[16,17] Therefore, the effects of exercise training on sprint performance are limited.[15–18]

Accordingly, athletes with already well-developed sprint abilities have to invest a lot of time and effort to additionally improve their performance.[15–18] Thus, sprint drills and CoD tasks should be implemented during the early stages of long-term athlete development to activate the available but limited adaptive reserves. To this end, coaches are constantly thriving to develop adequate training methods that help to develop promising young talents to elite soccer players. However, due to the specific characteristics of sprinting in soccer (i.e., linear sprints, back-forward sprints, CoD tasks), the question arises as to an appropriate training program to develop these soccer-specific physical qualities?

Ferrari Bravo et al. (2008)[19] demonstrated that 7 weeks of repeated-sprint training (3 × 6 maximal shuttle sprints of 40 m) with 3–4 sessions per week significantly increased performances in both, aerobic (Yo-Yo intermittent running test, level 1) and anaerobic (repeated sprint ability mean time) parameters in male soccer players aged 21 years. More recently, Sagelv and colleagues (2019)[20] compared the effects of a 22 weeks linear sprint versus CoD training with two sessions per week on intermittent high-intensity running performance in highly trained (U16–U19) Norwegian junior soccer players. The results showed main effects of time but no group × time interactions for the Yo-Yo intermittent recovery test ($p = 0.002$). In addition, no performance improvements were found for linear sprint speed and VO_{2max}. Moran et al. (2017b)[21] investigated the effects of linear sprint training on sprint performances (i.e., 10-m and 20-m) and the agility 5-10-5 test in young male soccer players aged 9–12 years of differing maturity status (pre and mid peak-height-velocity [PHV]). The results showed that this training type induced substantially larger effects in all tests in pre-compared with mid-PHV boys (Moran et al., 2017b).[21] In their narrative review, Rumpf et al. (2012)[22] included studies which explored the effects of specific sprint training (e.g., linear sprint training and resisted or assisted sprint training) versus non-specific sprint training (e.g., strength and power training, plyometric training, and combined training) on sprint time in male youth aged 8–18 years. These authors observed that plyometric training had the largest effect on sprint times in pre and circa peak-height-velocity participants, while the combined training methods were the most effective in post peak-height-velocity participants. In their second narrative review paper, the same authors [23]examined the effects of different sprint protocols on sprint performances in male participants aged >18 years. As an outcome of this article, the authors stated that in accordance with the principle of training specificity, specific sprint training methods had the largest effects on the examined sprint distances (i.e., (0–10, 0–20, 0–30, and 31+ m). Finally, the meta-analysis of Moran et al. (2017a) [24]included three studies that examined the effects of sprint training on sprint performance in pre, circa, and post pubertal soccer players. The authors observed that sprint training improved sprint performance in youths, but results were heterogeneous. Interestingly, sprint training was more effective with increasing maturity. Of note, none of these studies examined the effects of linear sprint speed versus CoD speed training on soccer-related physical fitness qualities in young soccer players. Thus, to the authors' knowledge, there is no study available that examined the effects of linear sprint speed versus CoD speed training on soccer-related physical fitness qualities in young soccer players according to age.

Accordingly, the primary aim of this study was to compare the effects of two different sprint training regimes (i.e., linear sprints *vs.* CoD sprints) on sprint and jump performances in highly trained U15, U17, and U19 soccer players over the course of one soccer season. Based on the relevant literature,[14.15.19.21-24] we hypothesized that i) larger improvements would occur with CoD sprint training compared with linear sprint training and ii) these improvements would be greater in younger compared with older players (i.e., U15 > U17 > U19).

Methods

Fifty-five adolescent elite soccer players (U19 [n = 18, 17.6 ± 0.5 years], U17 [n = 18, 16.0 ± 0.5 years], and U15 [n = 19, 14.6 ± 0.6 years]) were recruited from the Mohammed VI Academy of Soccer, Rabat, Morocco to participate in this study. Players were randomly assigned to two training groups (see Fig. 1 and Table 3); group 1 performed CoD sprints (CODST, n = 27; U19 [n = 9], U17 [n = 9], U15 [n = 10]), group 2 conducted linear sprints (LST, n = 28; U19 [n = 9], U17 [n = 9], U15 [n = 9]). The sample consisted of young male soccer players, who were part of a player development program of the Academy Mohammed VI. Players were selected and integrated at the age of 14 years for a training program that would last ~5 years. During the selection process, hundreds of boys from different parts of Morocco were evaluated and selected by coaches of the Academy Mohammed VI.

Human subject's ethical approval was provided by the Mohammed VI ethics committee of the Soccer Academy (2016–002) and the study was conducted in accordance with the latest version of the declaration of Helsinki. Parents and legal representatives provided written informed consent for study participation before the training program started.

Experimental design

The study was carried out over a period of seven months from September 2015 to April 2016 (=30 weeks). The training was performed from Tuesday to Saturday and included on average 12 h of training per week. All participating players were enrolled in the Academy at least one year before the start of the study (maximum six years) and evolved in their age group (U15, U17, U19). They all participated in the speed training (i.e., CoD or linear sprint) and regular soccer training program which included six physical and soccer-specific training sessions per week, which were endurance

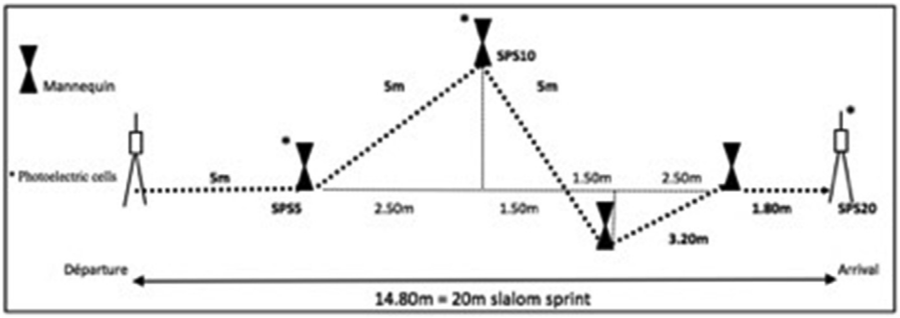

Fig. 1. 20-m sprint slalom test (SPS).

training, high intensity and sprint training, strength and power training, flexibility training, and training of technical-tactical drills (Appendix A). During the study period, players played 40 ± 6 games. All players had the same diet during training and consumption of ergogenic aids was prohibited. The test battery was carried out over three successive days during pre (T0) and post-tests (T1). A 48 h rest was provided before testing. Anthropometric characteristics (body height, mass, body fat %), and countermovement jump performance (CMJ) were collected on the first day. On the second test day, the 20-m linear sprint (SP: 0-5-10-20 m) and slalom sprint tests (SPS: 0-5-10-20 m) were performed. On the third test day, the maximum aerobic speed (MAS) test was scheduled. Tests were conducted in the same location (synthetic field and gym) and test sequence, and at the same time of day, and. Before testing, participants performed a standardized warm-up of 10 min of running, movements of the arms, trunk and lower limbs, 2 min of dynamic stretching (quadriceps, hamstrings, triceps, adductors, gluteal and iliopsoas), and 5 min of sprint drills (rectilinear, angular and shuttle). It is important to note that all players lived in the Academy during the week except for the weekends when they returned to their soccer teams for match play. Consequently, nutrition and hydration habits were well controlled by the nutritional staff during the time at the soccer academy. For the weekends, all players received nutritional guidelines and information on their diet. Hence, the two groups (LST and CODST) were well-controlled in terms of their eating and drinking behavior which is why are positive to rule out that differences in diet or hydration affected the outcomes of this study.

Assessment of anthropometric characteristics

The same trained technician measured stature, body mass, and two skinfold thicknesses (triceps and subscapular) following standard procedures.[25]

Intra-observer technical errors of measurement for stature (0.27 cm), body mass (0.47 kg), and skinfolds (0.47–0.72 mm) were within the range of several health surveys from the United States and a variety of field surveys, including studies of young athletes.[2]

Percentage of body fat was estimated from age and gender-specific anthropometric equations.[26]

A practical method of predicting years from PHV was used as a measure of maturity offset with body height, sitting height and chronological age as key variables to be included in the equation (PHV = −9.236 + (0.0002708 x leg length and sitting height interaction) + (−0.001663 x age and leg length interaction) + (0.007216 x age and sitting height interaction) + (0.02292 x weight by height ratio). This equation has been validated by Mirwald et al. (2002).[27] PHV (mean ± SD) was assessed at the start and at the end of the season for each age group (U15, U17, U19) (Appendix B).

Training and age group-specific anthropometric data were reported in Table 1 for pre and post-tests, separately.

Assessment of selected measures of physical fitness

Linear sprint test (SP): Linear sprint performance was evaluated using a 10-m standing start sprint test. Four pairs of telemetric photoelectric cells were placed 0.75 m above ground at the start line (0-m), after 5-m, and 10-m (Smart Speed, Fusion Sport, Australia). Split run times for 5-m (SP5) and 10-m (SP10) were used for further analysis. For the SP test, excellent test-retest reliability was recorded with an intraclass correlation coefficient (ICC) of 0.96 and a coefficient of variation (CV) of 3.5%.

Slalom sprint test (SPS): The test set up for the SPS is presented in Fig. 1. The 10-m slalom test (SPS10) used four mannequins, which were placed at 5-m (SPS5) and 10-m (SPS10) during the test. Players had to quickly run around the mannequins without touching them. The player started without verbal command with the preferred leg behind the starting line (0.3 m behind the first timing gate). Timing began as the athlete crossed the first pair of photocells. Each player performed two sprints with 1 min of recovery between each trial. The trial with the shortest time was used for further analysis. During the recovery period, players walked back to the starting line and waited for 2 min until the next sprint started. During the 2 min recovery period, each player maintained a low level of physical activity to be ready for the next test. For the SPS test, excellent test-retest reliability was recorded with an ICC = 0.93 and CV = 4.2%.

Countermovement jump test (CMJ): This test is a proxy for the assessment of lower limb muscle power. The CMJ was performed on a smart jump portable force platform (Fusion Smart Speed Jump, Fusion Sport, Australia). Players were instructed to perform a plyometric movement as fast as possible. They started from an upright erect standing position and made a preliminary downward movement by flexing the knees and hips to a knee angle of approximately 100°. This was immediately followed by a maximal acceleration of the center of mass in a vertical direction. The best trial out of two trials in terms of jump height was used for further analysis. For the CMJ test, excellent test-retest reliability was recorded with an ICC = 0.90 and CV = 4.6%.

Maximum aerobic speed test (MAS): The test consisted of a 200-m run with cones placed every 20-m using the University of Bordeaux - 2 incremental speed test (UB2T). Players ran for 3 min with 1 min of rest between each trial. The speed at the beginning of the test amounted to 8 km h^{-1} and it was increased in increments of 2 km h^{-1} for each new run. An acoustic signal provided feedback for the players regarding the pace at each speed level (Berthoin, Gerbeaux, Turpin, et al., 1994).[28] For the MAS test, acceptable test-retest reliability was recorded with an ICC value of 0.89 and a CV of

Table 1
Baseline anthropometric characteristics for the two intervention groups (LST vs. CODST) according to age categories (U15, U17, U19). Data are means ± SDs and 90% confidence intervals.

	LST (n = 28) (mean ± SD) [CI]			CODST (n = 27) (mean ± SD) [CI]		
Variables	U15 pre (n = 10)	U17 pre (n = 9)	U19 pre (n = 9)	U15 pre (n = 9)	U17 pre (n = 9)	U19 pre (n = 9)
Age (year)	13.4 ± 0.6 [13.7–14.4]	16.1 ± 0.6 € [15.4–16.1]	18.3 ± 0.5 $£ [17.5–18.5]	13.5 ± 0.8 [13.8–14.6]	15.9 ± 0.4 € [15.1–15.8]	18.1 ± 0.5 $£ [17.2–18.3]
Standing height (cm)	154.6 ± 7.2 £ [150.3–158.7]	165.6 ± 6.6 $ [161.4–169.6]	177.9 ± 5.1 ££ [174.8–181.1]	155.3 ± 7.6 € [150.6–160.1]	165.9 ± 9.2 $ [154.0–177.8]	177.2 ± 6.1 ££ [173.4–181.0]
Sitting height (cm)	76.1 ± 2.9 £ [74.4–77.8]	82.7 ± 3.6 $ [80.5–84.9]	87.9 ± 1.7 ££ [86.7–89.1]	77.7 ± 2.9 € [75.8–79.5]	86.4 ± 3.9 $ [84.0–88.8]	89.9 ± 3.4 ££ [87.8–92.0]
Body mass (kg)	40.5 ± 6.5 ££ [36.7–44.3]	51.0 ± 6.8 $$ [46.8–55.3]	63.1 ± 3.9 ££ [60.7–65.5]	43.2 ± 5.5 €€ [39.8–46.6]	57.6 ± 6.5 $$ [53.5–61.6]	63.9 ± 4.8 ££ [61.1–66.5]
Fat mass (%)	5.6 ± 1.3 [4.9–6.4]	5.6 ± 1.3 $ [4.8–6.5]	6.9 ± 1.6 ££ [5.9–7.8]	5.8 ± 1.2 € [5.05–6.5]	6.3 ± 1.0 $$ [5.7–6.9]	7.2 ± 1.3 ££ [6.4–8.0]
Peak-height-velocity	−0.6 ± 0.5 [-0.7 – (−0.4)]	1.3 ± 0.4 [1.3–1.8]	3.3 ± 0.5 [3.4–3.8]	−0.4 ± 0.5 [-0.7–0.5]	1.5 ± 1.0 [0.9–2.3]	3.1 ± 0.5 [3.3–3.8]

CODST = change-of-direction sprint training; LST = linear sprint training, $: Significantly different between U19 and U17, $: $p < 0.05$; $$: $p < 0.01$. £: Significantly different between U19 and U15, £: $p < 0.05$; ££: $p < 0.01$. €: Significantly different between U15 and U17, €: $p < 0.05$; €€: $p < 0.01$.

2.7%. The test ended if players were no longer able to follow the pace of the acoustic signal.

Training programs

Before each 30 min speed training session, participants performed a standardized warm-up program which included 3 min of running, 2 min of dynamic stretching (quadriceps, hamstrings, triceps, adductors, glutes, and iliopsoas), and 5 min of sprint drills (rectilinear, angular and shuttle). The first session started 48 h after the weekend match. The second session was conducted 72 h after the first session and at the same time of day.

Change-of-direction sprint training (CODST)

CODST consisted of 3 short, intense and varied COD sprint exercises over a cumulative distance of 20 m in 5 s intervals and a recovery period of 25 s (Fig. 1). The weekly training volume was 4 sets of 10 repetitions, which is equivalent to a total number of 1200 sprints over 30 weeks (i.e., 40 repetitions x 30 weeks = 1200).

Linear sprint training (LST)

LST consisted of 20-m shuttle sprints (10 m back and forth) with a 25 s recovery period between sprints. The weekly training volume was 2 sets with 10 repetitions each (round trip). A total distance of 400 m was covered and overall 1200 sprints were performed within the 30 weeks intervention period.

Statistical analyses

An a priori power analysis was computed (*N.B.*, expected SD of residuals = 0.1 s for 20-m linear sprint and 0.2 s for 20-m slalom sprint, desired power = 0.80, and alpha error = 0.05) to simulate a statistically significant main effect of group (F test family, ANCOVA) for our primary outcome linear sprint performance.[29] The analysis revealed that a sample size of n = 7 per age group would be sufficient to achieve medium-sized main effects of group at post.

Normal distribution was examined and confirmed using the Kolmogorov-Smirnov test. For statistical analyses, an analysis of covariance (ANCOVA) was computed with group (LST vs CODST) and age (U15: LST vs CODST; U17: LST vs CODST; U19: LST vs CODST) as between-subject comparators and baseline data as covariate. Notably, this method has been proposed as the most sufficient statistical approach for the analysis of continuous outcomes in randomized controlled trials.[30] Effect sizes (ES) were calculated from ANCOVA output by converting partial eta-squared to Cohen's *d*. Moreover, within-group ES were obtained using the equation ES = (mean post − mean pre)/SD. ES of 0.20–0.60, 0.61–1.19 and ≥ 1.20 were considered as small, moderate and large, respectively.[31] In general, descriptive data were presented as baseline adjusted group mean values and standard deviations. Additionally, group specific pre-to-post-test changes were presented as group mean values, standard deviations, and 90% confidence intervals (CI).

Performance changes from pre-to-post were calculated according to the following equation: (pre-test values − post-test values)/pre-test values × 100.

Intra-class correlation coefficients (ICC) and coefficients of variation (CV) were computed to assess relative and absolute test-retest reliability. A value of $p < 0.05$ was accepted as the minimal level of statistical significance. All analyses were performed using SPSS for Windows, version 16.0; SPSS Inc (Chicago IL, USA).

Results

During the 7-months experimental period, all players were able to complete the study according to the previously described study design and methodology. No injuries related to training or testing occurred over the course of the experimental period. During the intervention period, attendance rates amounted to 93 ± 4% for all experimental groups.

Anthropometric characteristics were determined pre and post training for all participants. No statistically significant between-group baseline differences were detected if the experimental groups (LST and CODST) were pooled across the age groups ($0.071 < p < 0.954$; $0.077 < d < 0.578$, small) (Appendix B). However, significant between group baseline differences were detected when comparing the experimental groups according to the different age categories (U15 vs. U17; U15 vs. U19; U17 vs. U19) (Table 1).

Table 2 contains age group specific physical fitness data (U15, U17, U19) at baseline. Significant between group differences (U15 vs. U17; U15 vs. U19; U17 vs. U19) were observed for selected outcome measures (i.e., age, standing height, sitting height, body mass, fat mass and peak-height-velocity).

Table 3 contain baseline-adjusted means, standard deviations and 90% confidence intervals at post for U15, U17, and U19 (LST vs. CODST). All physical fitness tests showed significant main effects of time (post-test > pre-test, $p = 0.005$ to $< p < 0.002$) for all groups (U15, U17, U19) with ES magnitudes, for all tests, ranged from small to moderate ($d = 0.30–0.80$). For all physical fitness measures, the

Table 2

Baseline physical fitness data for LST and CODST according to age categories (U15, U17, U19). Data are means ± SDs and 90% confidence intervals.

	LST (n = 28) (mean ± SD) [CI]			CODST (n = 27) (mean ± SD) [CI]			Difference (mean ± SD) [CI]		
Variables	U15 (n = 10)	U17 (n = 9)	U19 (n = 9)	U15 (n = 9)	U17 (n = 9)	U19 (n = 9)	U15 LST - U15 CODST	U17 LST - U17 CODST	U19 LST - U19 CODST
MAS ($Km.h^{-1}$)	16.5 ± 0.0 [15.33−16.73]	18.1 ± 0.2 € [16.35−18.46]	16.9 ± 1.0 $£ [16.08−17.4]	16.0 ± 0.0 [15.58−16.27	16.6 ± 0.4 [15.58−16.88]	16.7 ± 0.1 [16.29−17.54]	−0.5 ± 0.29 [-1.04−0.02]	−1.53 ± 0.41 [-1.65−0.18]	−0.28 ± 0.57 [-0.88−1.24]
CMJ (cm)	26.7 ± 3.3 [24.67−28.74]	29.7 ± 4.2 € [26.94−32.45]	32.9 ± 3.9 $£ [30.35−35.58]	28.9 ± 2.5 [27.25−30.54]	34.5 ± 2.9 € [32.59−36.45]	36.6 ± 4.1 $£ [33.86−39.3]	2.19 ± 1.28 [-0.16−4.55]	4.82 ± 1.59 [1.85−7.78]	3.61 ± 2.59 [-1.21−8.44]
SP5 (s)	1.21 ± 0.07 [1.16−1.25]	1.14 ± 0.06 € [1.08−1.19]	1.20 ± 0.09 [1.14−1.25]	1.19 ± 0.07 [1.14−1.23]	1.17 ± 0.08 [1.11−1.21]	1.20 ± 0.08 $ [1.14−1.25]	−0.02± −0.03 [-0.07−0.04]	0.03 ± 0.042 [-0.05−0.1]	0.00 ± 0.036 [-0.06−0.06]
SP10 (s)	2.06 ± 0.09 [1.99−2.11]	1.95 ± 0.09 € [1.88−2]	1.94 ± 0.09 £ [1.87−1.99]	2.03 ± 0.10 [1.96−2.09]	1.93 ± 0.10 € [1.86−1.99]	1.94 ± 0.11 £ [1.85−2]	−0.03 ± 0.03 [-0.08−0.25]	−0.02 ± 0.047 [-0.18−0.16]	−0.03 ± 0.49 [-0.09−0.09]
SPS5 (s)	1.30 ± 0.22 [1.16−1.43]	1.22 ± 0.09 € [1.16−1.28]	1.23 ± 0.06 [1.18−1.26]	1.19 ± 0.03 [1.16−1.2]	1.20 ± 0.09 [1.14−1.26]	1.22 ± 0.09 [1.15−1.27]	−0.11 ± 0.07 [-0.26−0.028]	−0.02 ± 0.45 [-0.1 − 0.06]	−0.01 ± 0.038 [-0.08−0.06]
SPS10 (s)	2.28 ± 0.08 [2.15−2.4]	2.13 ± 0.11 [2.05−2.2]	2.07 ± 0.12 $ [1.99−2.14]	2.21 ± 0.03 [2.18−2.22]	2.12 ± 0.09 € [2.06−2.17]	2.10 ± 0.10 £ [2.03−2.17]	0.11 ± 0.07 [-0.23−0.01]	−0.01 ± 0.051 [-0.1−0.08]	−0.03 ± 0.05 [-0.06−0.13]

CODST = change-of-direction sprint training; CMJ: counter movement jump; LST = linear sprint training, MAS: maximal aerobic speed; SP5: 5-m linear sprint; SP10: 10-m linear sprint; SPS5: 5-m slalom sprint; SPS10: 10-m slalom sprint. $: Significantly different between U19 and U17, $: $p < 0.05$. £: Significantly different between U19 and U15, £: $p < 0.05$. €: Significantly different between U15 and U17, €: $p < 0.05$; €€: $p < 0.01$.

Table 3

Physical fitness test data for LST and CODST according to age categories (U15, U17, U19). Data are presented as baseline adjusted mean values ± SDs and 90% confidence intervals at post.

	U15 LST (n = 9)	U15 CODST (n = 9)			U17 LST (n = 9)	U17 CODST (n = 9)			U19 LST (n = 9)	U19 CODST (n = 9)		
Variables	POST (mean ± SD) [CI]	POST (mean ± SD) [CI]	Difference (mean ± SD) [CI]	p values (Cohen's d)	POST (mean ± SD) [CI]	POST (mean ± SD) [CI]	Difference (mean ± SD) [CI]	p values (Cohen's d)	POST (mean ± SD) [CI]	POST (mean ± SD) [CI]	Difference (mean ± SD) [CI]	p values (Cohen's d)
MAS ($Km.h^{-1}$)	16.67 ± 0.22 [16.29−17.05]	16.34 ± 0.23 [15.94−16.74]	0.33 ± 0.90 [-2.51−1.05]	0.314 (0.063)	17.26 ± 0.19 [16.93−17.6]	17.27 ± 0.19 [16.94−17.61]	0.01 ± 0.52 [-0.29−0.80]	0.976 (0.001)	17.44 ± 0.11 [17.24−17.64]	17.62 ± 0.11 [17.42−17.81]	0.18 ± 1.16 [-1.23−0.61]	0.300 (0.071)
CMJ (cm)	30.68 ± 0.67 [29.5−31.85]	30.78 ± 0.71 [29.54−32.03]	0.10 ± 0.91 [-0.47−1.11]	0.917 (0.001)	34.72 ± 0.79 [33.32−36.11]	37.89 ± 0.80 [36.5-39-29]	3.17 ± 3.84 [-5.97 - (−0.53)]	0.205 (0.310)	38.30 ± 1.11 [36.09−40.10]	39.1 ± 1.11 [37.40−41.41]	0.80 ± 2.16 [-2.65−0.46]	0.453 (0.038)
SP5 (s)	1.15 ± 0.02 [1.12−1.19]	1.14 ± 0.02 [1.1−1.18]	0.01 ± 0.06 [-0.04−0.09]	0.589 (0.019)	1.31 ± 0.03 [1.01−1.1]	1.057 ± 0.03 [0.99−1.08]	0.25 ± 0.06 [-0.03−0.06]	0.132 (0.145)	1.11 ± 0.21 [1.07−1.14]	1.08 ± 0.2 [1.04 −1.12]	0.03 ± 0.06 [-0.03−0.08]	0.392 (0.049)
SP10 (s)	2.25 ± 0.23 [2.14−2.36]	2.14 ± 0.06 [2.02−2.25]	0.11 ± 0.23 [-0.06−0.30]	0.236 (0.087)	2.07 ± 0.13 [1.8 −1.9]	1.79 ± 0.12 [1.79−1.89]	0.28 ± 0.09 [-0.06−0.09]	0.285 (0.076)	1.85 ± 0.032 [1.79−1.90]	1.84 ± 0.03 [1.78−1.90]	0.01 ± 0.09 [-0.07−0.09]	0.900 (0.001)
SPS5 (s)	1.14 ± 0.01 [1.12−1.17]	1.13 ± 0.01 [1.1−1.16]	0.01 ± 0.06 [-0.02−0.05]	0.516 (0.027)	1.24 ± 0.14 [1.01−1.26]	1.18 ± 0.14 [1 −1.21]	0.06 ± 0.11 [-0.08−0.112]	0.826 (0.003)	1.05 ± 0.03 [1.01−1.10]	1.09 ± 0.02 [1.04−1.14]	0.039 ± 0.11 [-0.12−0.04]	0.337 (0.061)
SPS10 (s)	2.15 ± 0.02 [2.11−2.2]	2.15 ± 0.02 [2.1−2.19]	0.01 ± 0.05 [-0.05−0.07]	0.887 (0.001)	2.28 ± 0.14 [2.03−2.35]	1.97 ± 0.13 [1.89−2.15]	0.31 ± 0.14 [-0.12−0.08]	0.264 (0.083)	2.07 ± 0.04 [2.00−2.14]	2.07 ± 0.03 [2.00−2.14]	0.00 ± 0.16 [-0.12−0.10]	0.999 (0.039)

CODST = change-of-direction sprint training; CMJ: counter movement jump; LST = linear sprint training, MAS: maximal aerobic speed; SP5: 5-m linear sprint; SP10: 10-m linear sprint; SPS5: 5-m slalom sprint; SPS10: 10-m slalom sprint.

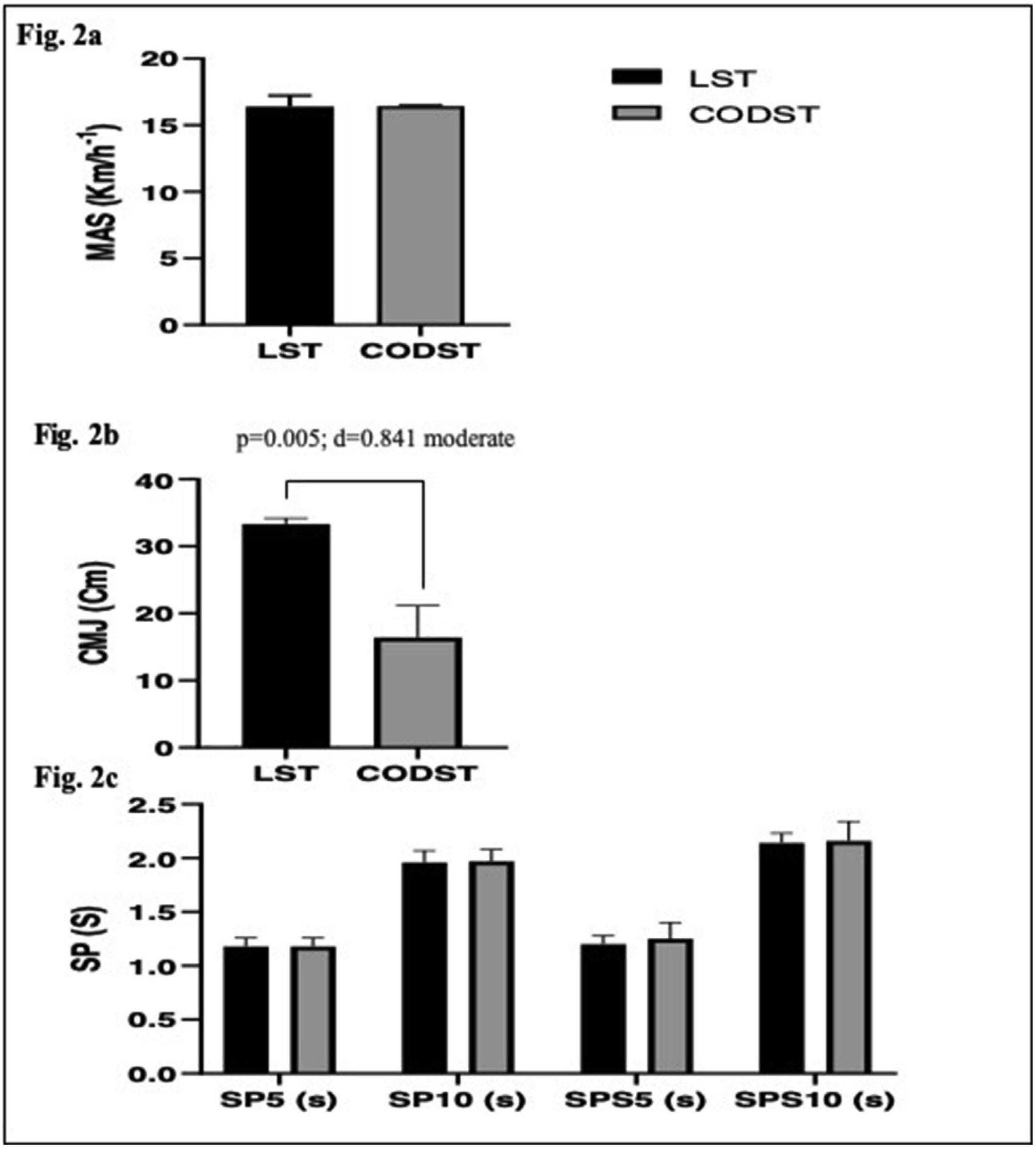

Fig. 2. Baseline physical fitness data for LST and CODST (Fig. 2a, MAS (Km/h); Fig. 2b, CMJ (cm); Fig. 2c, SP (s)). Data were pooled across age groups and presented as means ± SDs. LST: linear sprint training, CODST: change of direction sprint training, MAS: maximal aerobic speed, CMJ: counter movement jump, SP: sprint.

analyses revealed no significant differences between LST and CODST for U15, U17, and U19 at post.

Appendix Cpooled data across the age groups showing pre-post changes for physical fitness outcomes according to the experimental groups (LST, CODST). Appendix D contains group-specific pre-post changes for physical fitness outcomes according to the age categories (U15, U17 and U19).

Fig. 2 presents group-specific (LST; CODST) baseline data for physical fitness outcomes (Fig. 2a, MAS (Km/h); Fig. 2b, CMJ (cm); Fig. 2c, SP (s)), which were pooled across the age groups. A significant difference was found for CMJ ($p = 0.005$; $d = 0.841$ moderate).

Fig. 3 presents pooled data across the age groups showing pre-post changes for physical fitness outcomes according to the experimental groups (LST, CODST) (Fig. 3a, MAS (Km/h); Fig. 3b, CMJ (cm); Fig. 3c, SP (s)). In addition, baseline-adjusted means, standard deviations and 90% confidence intervals are illustrated at post for LST and CODST. Similarly, significant main effects of time (post-test > pre-test, $p = 0.005$ to $p < 0.001$) for both groups (LST and CODST) with effect size (ES) magnitudes for all tests ranging from small to moderate ($d = 0.19–0.75$).

For all physical fitness measures, the results showed no significant differences between LST and CODST at post.

Discussion

This study aimed to elucidate the effects of two different sprint-training regimes on selected measures of physical fitness in U15, U17, and U19 elite soccer players. To our knowledge, this is the first sprint-training study that has been conducted in young elite soccer players according to age over the course of an entire soccer season (i.e., 7-months). The results showed that both sprint training regimes (CoD sprint and linear sprint) induced significant changes in sprint, lower limb power, and aerobic performance. Furthermore, age appeared not to have an impact on the findings.

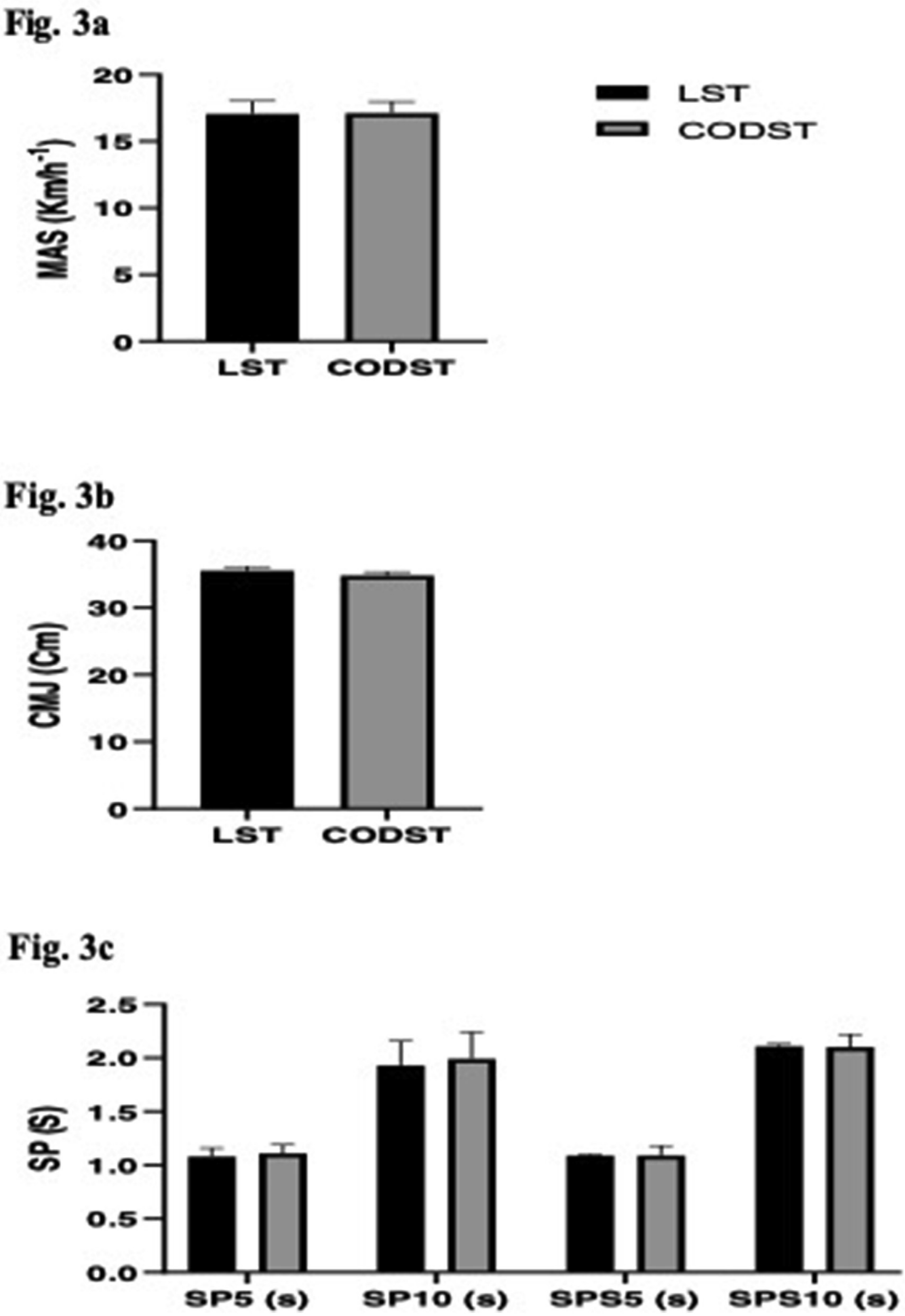

Fig. 3. Physical performance data for LST and CODST (Fig. 3a, MAS (Km/h); Fig. 3b, CMJ (cm); Fig. 3c, SP (s)). Data were pooled across age groups and presented as baseline adjusted mean values ± SDs at post. LST: linear sprint training, CODST: change of direction sprint training, MAS: maximal aerobic speed, CMJ: counter movement jump, SP: sprint.

Linear sprint ability over short distances is the most common type of movement before goal scoring and represents the basis for most speed training programs.[32] Results of the present study showed significant performance changes in 0 to 5–10 m, as well as in aerobic endurance (MAS) and lower limb muscle power (CMJ). Our findings are in accordance with much of the prior reported literature. Kotzamanidis et al. (2013)[33] and Venturelli et al. (2008)[34] examined pre-PHV subjects and observed a significant improvement in sprint performances (10, 20 and 30 m sprint time) following 12 weeks of linear sprint training. Two recent reviews[24,35] reported a significant improvement in sprint velocity (ES = −0.71 to −0.92 and ES = 0.43 to 1.59, respectively) with a moderate heterogeneity between maturity-groups. In the same context, a significant improvement in agility and jump performance has been reported following linear sprint training.[36]

The significant performance changes in terms of physical fitness in the current study may relate to improvements in technical adaptations such as increased step length,[37,38] a reduced contact time during acceleration,[39] an improvement in lower limb strength and ground reaction forces,[39] and/or an improvement in body coordination.[36]

Sprinting while changing directions rapidly has been considered as an important prerequisite for performance in team sports, especially soccer. In this sense, repeated-shuttle sprint training has been proposed as a new form of conditioning by combining repeated sprint exercises and CoD activities.[40] In the present study, power performance and linear sprint speed improved following linear sprint training. These results are in line with several studies. For example, Buchheit et al. (2010)[41] reported a significant increase of 30-m sprint performance and the CMJ and hop-test in elite soccer players (U15) following 10 weeks of shuttle sprint training. Also, Chaalali et al. (2016)[42] showed a significant improvement in linear sprint speed (15-m with and without the ball) and CoD performance following a specific training program (CoD exercises with/without the ball) of 6 weeks duration in young elite soccer players (U15). Recently, better CMJ, agility, and sprint performances were reported among young soccer players (10–12 years old) following 8 weeks of specific training (CoD and plyometric exercises) compared to pre-training performances.[43]

Several factors may explain the possible physical improvements after training. But, an improvement in lower limb strength due to a high number of turns maybe represents the most plausible factor. Indeed, as mentioned by previous studies, changing direction requires high braking forces (deceleration) followed by propulsive forces (acceleration),[44] resulting in a greater lower limb strength demand. It has been reported that knee flexors/extensors hip extensors and plantar flexors muscles are highly solicited during a CoD movement, contributing to eccentrically decelerate the downward motion of the body's center of mass, to stabilize the knee joint and to contribute to the propulsion phase.[45]

Based on this aspect, and considering the importance of both horizontal and vertical forces production during varied sprint training, it could be speculated that the increase in performance following the varied training protocol is due to an improvement in lower limb strength/power and coordination. In that regard, a significant relationship was reported between lower limb strength and shuttle sprint performance and between strength and jumping performance.[46]

Another interesting result of the present study was the improvement in aerobic endurance (MAS) following the two training protocols. Similarly, Ferrari-Bravo et al. (2008)[19] observed a significant improvement in aerobic capacity following 7 weeks of repeated shuttle sprint in junior elite soccer players (U18). In our study, aerobic fitness changes are similar to those of Ferrari-Bravo's study (~6%). However, the players (U19) in the study conducted by Sagelv et al. (2019)[20] experienced no improvements in aerobic power following 22 weeks of repeated sprint exercise. These authors explained their results by higher baseline VO_{2max} and/or by the low weekly volume of repeated sprint exercise (2 × 360 m per week).

Despite the lower shuttle-sprint training volume per session (20-m shuttle sprints) used in our study compared to Dawson's study (up to 42 shuttle sprints per session), a significant improvement in aerobic capacity was found. Therefore, it appears the applied repeated linear sprint protocol provides an adequate stimulus to induce improvement in aerobic fitness. This finding can most likely be explained by muscular and cardiovascular adaptations induced by the training protocols.[19]

However, since the starting aerobic capacity of the present study's participants was relatively low, thus the level of improvement in aerobic performance observed was perhaps related to the low pre-training fitness level of the players. For example, in the study of Impellizzeri et al. (2008)[47] a significant improvement of ~7% improvements in aerobic capacity was observed after 4 weeks of training before the start of a competitive season, however, after completion of a further 8 weeks of training during the start of the competitive season they did not report any further improvement in aerobic fitness. Therefore, these different responses to training are probably related to some extent on the pre-intervention fitness and training level of the participants.

Despite that the training design of the two training programs, in the current study, being different (linear vs. CoD sprints), the protocols elicit similar improvement in sprint performances. Two main studies[13,40] compared performance, neuromuscular and metabolic responses of the shuttle (RSS) and the straight-line (RSL) repeated sprint running tests. Although they reported significant differences between tests in terms of mean time and best time, no glycolytic or neuromuscular capacity differences were highlighted between tests. Indeed it was reported[38] that no significant blood lactate concentration post-exercise differences existed between RSS and RSL (12.2 ± 3.3 mmol/L vs. 11.2 ± 2.4 mmol L-1 respectively). These results were similar to those obtained by Buchheit et al. (2010)[13] in young soccer players. Moreover, neuromuscular fatigue measured 1-min following RSS and RSL via a CMJ test revealed no significant differences between either of the two forms of tests.[13] However, recently Sagelv et al. (2019)[20] observed no improvement in sprint performance (10 and 20 m sprint) after 22 weeks of repeated sprint exercise (linear sprint vs. CoD sprint) in the young elite soccer players (U19). These authors explained their inconsistent results by their low repeated sprint exercise volume (90–800 m) and/or baseline characteristics of the players involved (e.g. initial fitness level).[20]

The lack of difference in terms of training impact following the two protocols proposed in the present study could be explained by the lack of dramatic neuromuscular and metabolic differences induces by training programs. Indeed, even though spiriting with CoD training protocol requires high braking and propulsive force which increase metabolic and neuromuscular demands, on the other hand, in the straight line training, due to biomechanical aspects such as higher stride length and better use of the stretch-shortening cycle, are developed higher running speed, requiring high muscle actions too. We acknowledge this is speculative on our part but is supported in the literature by a very strong relationship reported between the two forms of sprints.[48]

Relative to practical application, current evidence supports that the critical periods for speed training range between 5 to 9 and 12–15 years old.[39]

During the first phase (5–9 years), coordination, speed of movement and stride frequency should be developed before complete myelination of the nervous system. On the other hand, in the second phase (approximately around the onset of peak height velocity (PHV) and the onset of puberty), where a significant rise of hormone levels (testosterone and growth hormone) is detected, strength, power and sprinting ability should be developed.[39]

Given this information, appropriate training during this stage of maturation may be beneficial. To that end, comparisons between the three groups (U15, U17, U19) of the present study revealed no significant differences for fitness tests between groups. These results are in agreement with those reported by Moran et al. (2017a).[22] Indeed, in their meta-analysis (Moran et al., 2017b)[21] which aimed to compare the adaptability to sprint training across pre- (10–12.9 years old), mid- (13–15.9-year-old), and post- (16–18-year-old) PHV groups, results showed a high variation between groups. That is, the Pre- PHV group showed the smallest effect size for change in sprinting velocity compared to the two other groups. Results concerning the middle group indicated a moderate effect size. On the other hand, the post group showed the greatest effects on sprinting velocity. The variation in terms of sprint-training adaptability between age groups of the present study may be explained, at least in part, by the effect of maturity. In that regard, it has been reported that sprint training becomes progressively more effective with increasing maturity.[21]

It should be noted that the participants of the present study were assigned to three age groups (U15, U17, U19) according to their reported chronological age and not by their maturational status. This issue may represent one of the limitations of this investigation. Therefore, future studies might want to use the Tanner Stage determination when classifying young players, to incur a greater level of scientific control. We also acknowledge the incorporation of a control group who did not train. This would have added in determining the influence of maturation on our findings.

Conclusions

The results from this study showed that the two sprint training regimes (linear sprint and CoD sprint) induced significant changes in the sprint, lower limb power and aerobic performance in young elite soccer players. Furthermore, age appeared not to have an impact on our outcomes. Given that no significant differences were observed between LST and CODST, the observed changes can be due to training and/or maturation. Thus, coaches and fitness professionals can use either linear sprint or CoD methods to exercise sprint performances in young elite soccer players, irrespective of age.

Practical implications

Coaches and practitioners working within young elite soccer players generally support the usefulness of sprint training. Consequently, to improve sprint performances in this population it is recommended to use either linear sprint or CoD sprint training or a combination of both.

Author contributions

TP, CT, and HZ conceived and designed the research, TP and CT conducted the experiment. TP, IS, ABA and MR analyzed the data. TP, CT, UG, and HZ wrote and revised the manuscript. All authors read and approved the manuscript.

Funding sources

This research did not receive any specific grant funding from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The author would like to thank the players and the physical as well as medical staff for participating in this study. The authors acknowledge the support of the Deutsche Forschungsgemeinschaft (DFG) and Open Access Publishing Fund of the University of Potsdam, Germany.

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2020.10.003.

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