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Effects of Maturation Status on Physical Performance Adaptations Following a Combined 7-Week Strength and Power Training Program in Elite Male Youth Soccer Players

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Abstract

This study investigated the adaptations induced by a 7-week training protocol combining strength and power training with regular soccer training in young elite soccer players, considering their maturity level. Thirty-five participants were categorized into three training groups according to their maturation status. They were classified based on their relative age and peak height velocity (PHV) as: Pre-PHV, Mid-PHV, and Post-PHV. Each group engaged in a 7-week program, combining their regular soccer training with two resistance sessions per week (one strength and one power session). Before and after the training program, the following tests were conducted: eccentric hamstring strength using the Nordic Hamstring Exercise (NHE), countermovement jump (CMJ), sprint with split times at 10 and 30 m, and Change of Direction and Acceleration Test (CODAT). The Pre-PHV group exhibited significant improvements in sprint performance ($p < 0.02$), while the Mid-PHV and Post-PHV groups showed enhanced performance in CODAT ($p = 0.01$ and $p = 0.05$, respectively). Notably, the Post-PHV group displayed improvements in the NHE ($p < 0.05$), but also experienced a decline in sprint performance ($p < 0.01$). The training protocol produced substantial enhancements in 10 and 30 m sprint times for the Pre-PHV and Mid-PHV groups relative to the Post-PHV group ($p < 0.02$), while the Post-PHV group achieved greater advancements in NHE compared to the Pre-PHV group ($p < 0.01$). No significant differences were found between Pre-PHV and Mid-PHV groups across all assessed parameters ($p > 0.01$). These findings demonstrated that the same strength training program led to different adaptations depending on the participants' maturation status; therefore, this aspect should be carefully considered when designing training programs for young soccer players.

Keywords: strength training; power training; maturations status; youth soccer players; soccer; performance adaptations

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1. Introduction

Soccer is classified as an intermittent sport, in which players engage in short, high-intensity bouts of linear and multi-directional movements, interspersed with intervals of low-intensity activity during the match [1,2]. Over the years, soccer has evolved into a highly physically demanding sport, marked by a significant increase in the frequency and volume of high-intensity activities such as sprints, high-speed running, accelerations,

decelerations, and changes of direction, all of which are critical in determining match outcomes [3–6]. It is therefore assumed that enhancing players' physical abilities to perform these high-intensity actions will increase the team's chances of success [7]. For this reason, soccer training should be designed to enhance players' abilities to perform high-intensity actions during competition. Currently, it is well established that strength training, combined with sport-specific soccer drills, significantly improves sprinting, change of direction, and jumping performance in players [8,9]. Consequently, strength training has become a key component in the physical preparation of soccer players.

Although it is well established that strength training improves both physiological and physical parameters in professional soccer players [10], evidence also suggests that the recurrent use of strength training in young soccer players, both elite and amateur, has significant positive effects on their performance [11–14]. Likewise, it has been demonstrated that, in the short term, no improvements occurred in a control group performing only soccer training compared to an intervention group that included regular strength training and exhibited improved performance in the 10 m sprint test, agility, and vertical jump [15,16]. The positive effects of strength training include improvements in high-intensity actions and a reduction in injury incidence compared to young players who do not engage in this type of training [17].

One of the most important factors to consider when training strength in young athletes is their biological age, as it is well established that biological maturation can influence specific strength-training adaptations [18,19]. Monitoring and assessing biological maturation in young soccer players is an important aspect of controlling its influence on performance [20]. This approach helps to ensure that training programs are tailored to the individual's capabilities, helping players to improve their performance under equal conditions [21]. Regarding the individualization of strength training, it has been proposed that there is a "window of optimal trainability" during which strength development is at its optimal level, typically occurring 12 to 18 months after peak height velocity (PHV) is reached [22]. This is caused by an increased concentration of circulating hormones, which facilitate enhanced muscle anabolism, resulting in greater gains in strength and hypertrophy following specific strength training [23]. A recent meta-analysis has corroborated this assertion, demonstrating that strength training yields more substantial positive effects in young athletes who have reached PHV [24]. A period of "accelerated adaptations" has also been suggested for the development of speed and power [25]. Because of a variety of factors, including hormonal, muscular, and mechanical influences, it is suggested that the ideal time to develop these qualities in males is between 12 and 16 years of age [25].

In the context of soccer, it is well established that strength training provides significant advantages for young athletes; however, there is still ongoing debate regarding the most effective training approaches based on the maturity levels of these players. While existing evidence suggests that strength training tends to yield more pronounced benefits after the PHV stage [24], the influence of maturation on the efficacy of plyometric training remains less definitive. Several studies stratifying participants by maturation status (including at least one pre-PHV and one post-PHV group) and incorporating plyometric training alongside conventional soccer practices have yielded inconsistent findings, with some reporting greater performance improvements in the pre-PHV group [26] and others in the post-PHV group [27,28]. For instance, Asadi et al. [27] reported improvements in vertical jump and sprint performance in both intervention groups following a 6-week plyometric regimen, with the post-PHV group exhibiting superior gains. Conversely, Vera-Assaoka et al. [26] documented greater advancements in the pre-PHV group in drop jump and kicking distance tests following a 7-week plyometric training protocol.

On the other hand, previous literature has suggested that a training approach combining high-load strength exercises with low-load movements focused on speed could effectively enhance power output [29], strength, and body composition [30]. The training protocol used in these studies aligns with the competitive microcycle of soccer and is specifically designed to optimize training load management. This protocol aims to accumulate a higher load in the middle of the microcycle, reducing the load towards the end, with the goal of implementing a tapering strategy. To our knowledge, there is a lack of research investigating the effects of this specific training protocol, designed to align with the structure of an in-season microcycle, while also considering the maturation status of elite young soccer players. For this reason, the objective of this study was to investigate the effects of a 7-week training protocol combining strength and power training with regular soccer training in young elite soccer players, considering their maturity level. It was hypothesized that, regardless of the players' maturation status, all participants would show improvements in performance after the training program, with those in the later stages of maturation expected to report greater improvements.

2. Materials and Methods

2.1. Participants

Thirty-five healthy elite male youth soccer players (14.3 ± 1.4 years) from the same academy participated in this study. Prior to the training sessions, the maturational status of all participants was assessed, including their body mass, standing height, and sitting height. In accordance with the analyses of previous authors [31], these values were input into an equation to estimate the players' maturity level: maturity offset = −9.236 + (0.0002708 × leg length × sitting height) + (−0.001663 × age × leg length) + (0.007216 × age × sitting height) + (0.02292 × body mass/body height ratio). In accordance with the guidelines established by these authors, three training groups were formed based on the players' maturational status: Pre-PHV (−3 to > −1 years from the PHV), Mid-PHV (−1 to +1 year from the PHV), and Post-PHV (>1 to +3 years from the PHV). Based on these considerations, the groups were structured as follows: Pre-PHV: n = 9 (age: 12.9 ± 0.4 years; height 151.8 ± 4.4 cm, weight: 39.1 ± 5.2 kg), Mid-PHV: n =14 (age: 13.9 ± 0.7 years; height: 164.9 ± 6.4 cm; weight: 51.6 ± 9.0 kg) and Post-PHV: n =12 (age: 15.8 ± 0.9 years; height: 171.5 ± 5.9 cm; weight: 59.3 ± 5.9 kg).

All subjects normally participated in five team training sessions (~7 h) and one official match per week. To be included in the study, participants were required to attend at least 85% of both resistance training sessions and specific team training sessions, following the protocols established in prior literature [32]. Based on this inclusion criterion, 24 out of the 59 initially enrolled participants were excluded (40.7%), resulting in a final sample of 35 for analysis. Data used in this study were collected through daily monitoring and testing conducted as part of the team's training regimen throughout the competitive season. As such, ethical approval from a committee was deemed unnecessary [33]; however, the study adhered to the principles outlined in the Declaration of Helsinki, and prior to participation, players were informed about the study's objectives, experimental procedures, and any associated risks.

2.2. Study Design

During the final phase of the 2023–2024 season, all participants followed a 7-week training protocol, which included two weekly resistance training sessions in addition to their regular soccer-specific on-field training (see Table 1 for session details). Both resistance training sessions were conducted in the gym, but they had different objectives. The first session, which focused on strength development (comprised of Strength Session A and

Session B; see Table 1 for further details), was performed 4 days before the match, to ensure that players had sufficient time to recover, particularly from eccentric-type efforts [34]. These trainings were carried out at the end of the soccer practice and lasted approximately 30–40 min. To avoid excessive monotony and to stimulate the players through movement variations, Sessions A and B were alternated weekly. The second resistance training session took place 2 days before the match, just before soccer practice. This session was shorter (lasting approximately 25–30 min) and focused on power development. In this case, the intensity of the selected exercises was determined by the participants based on the prescribed number of repetitions and their perception of form, following the autoregulation principle [35]. This approach has been reported as effective, presumably due to a better balance between the desired and actual training stimulus [36]. All participants were already familiar with both types of training.

Table 1. Content of the two strength and power sessions.

Strength Session A	**Sets**	**Reps**	**Intensity**	**Rest**
Sliding leg curl	2	6	Body weight	2 min
Back squats	2	8	~80% 1 RM	2 min
Side plank (Copenhagen variation)	2	20 s per side	Body weight	1 min 30 s
Dumbbells reverse lunges	2	6 per side	~70% 1 RM	1 min 30 s
Rotational Pallof press	2	8 per side	-	1 min
Bench press	2	8	~80% 1 RM	1 min 30 s
TRX pulls	2	15	~65% 1 RM	1 min 30 s
Strength Session B	**Sets**	**Reps**	**Intensity**	**Rest**
Barbell deadlift	2	6	~85% 1 RM	2 min
Rear-foot elevated split squat	2	6 per side	~85% 1 RM	2 min
Sliding hip adduction	2	8 per side	Body weight	1 min 30 s
Kettlebell standing calf raises	2	10 per side	~75% 1 RM	1 min 30 s
Anti-rotation Pallof press	2	8 per side	-	1 min
Cable chest fly	2	8	~80% 1 RM	1 min 30 s
Single arm dumbbell row	2	8 per side	~80% 1 RM	1 min 30 s
Power Session	**Sets**	**Reps**	**Intensity**	**Rest**
Medicine ball chest pass	2	3	4–6 kg	2 min
Lateral bounds	2	3 per side	Body weight	2 min
Jump onto box	2	5	60–70 cm height	2 min
Drop Jumps	2	4	30 cm height	2 min
Band-resisted sprints (~7 m)	2	5	Band resisted	2 min
Band-resisted lateral shuffles (~5 m)	2	3 per side	Band-resisted	2 min

RM: repetition maximum.

2.3. Testing Protocol

Physical assessments were carried out both before and after the 7-week training intervention. All evaluations took place across two consecutive days, with a 24 h gap between them, to allow for normal training and to prevent fatigue accumulation that could affect the players' performance. In the 48 h prior to the start of the tests, the participants were instructed to refrain from any physical activity. On the first day, participants performed the countermovement jump (CMJ) followed by a 30 m linear sprint. The second day in-

volved the eccentric hamstring strength test using the NordBord device (Vald Performance, Newstead, Australia) and the Change of Direction and Acceleration Test (CODAT). Prior to each testing session, a 15 min standardized warm-up was completed, including light running, dynamic mobility drills, and specific preparatory exercises aligned with the tests that followed.

2.3.1. Countermovement Jump Test

To assess lower-limb explosive power, participants completed three countermovement jumps (CMJs) on a SmartJump platform (Vald Performance, Newstead, Australia, https://www.vald.com; accessed on 25 April 2022). During each jump, they maintained their hands positioned on the hips, selected their own countermovement depth, and ensured they landed upright with a controlled knee flexion immediately after ground contact, in accordance with protocols used in previous studies [37]. In cases of incorrect landings, the attempt was repeated, consistent with the methodology employed in previous research [38]. Each jump was separated by 45 s of passive recovery to avoid the accumulation of fatigue. The best attempt was recorded for subsequent statistical analysis.

2.3.2. Nordbord Test

Eccentric hamstring strength (NHE) was measured using the NordBord testing device (Vald Performance, Newstead, Australia). Participants knelt on the platform with their ankles secured to the load cells, which recorded the vertical force produced by each leg independently. A standardized warm-up preceded testing and consisted of three sets of three repetitions performed at progressively greater intensities (approximately 70%, 80%, and 90% of perceived maximal effort). Participants then completed three maximal-effort repetitions, following previously described procedures [39]. Throughout the test, participants maintained their hands crossed over their chest, using them only if necessary to control their descent, and were encouraged to resist the forward movement for as long as possible while keeping their body aligned from shoulders to knees. The knee position was documented to ensure consistency and reproducibility between pre- and post-intervention assessments.

To assess overall hamstring eccentric strength, the force measurements from both the right and left legs were averaged. The highest recorded trial from this averaged data was then used for subsequent statistical analysis.

2.3.3. Linear Sprint Test

Sprint ability was assessed using a photoelectric timing system (SmartSpeed, Vald Performance, Newstead, Australia, https://www.vald.com; accessed on 25 April 2022) over a 30 m linear track, with split times captured at 10 m. To better reflect typical football movements, participants started from a standing position, placing their front foot about 50 cm behind the first timing gate, and initiated the sprint at a self-selected moment, following established testing protocols [40]. The sprint commenced when participants felt ready, in order to eliminate any reaction time bias [41]. Participants completed two maximal effort sprints, with 2 min of rest between attempts. The best sprint time, recorded to the nearest 0.01 s, was used for subsequent statistical analysis.

2.3.4. CODAT

The Change of Direction and Acceleration Test (CODAT) was employed to evaluate change-of-direction speed. Previous research has documented the test's validity and reliability for field sports [42]. To measure the time required to complete the entire test distance, two timing gates (Vald Performance, Newstead, Australia) were used, positioned at the starting and finishing points. As in the previous tests, participants were instructed

to begin from a standing position, with their leading foot 50 cm behind the first timing gate [41]. Participants were required to step outside the designated cones using both legs [43]. If a cone was displaced during the trial, it was repeated. Cones measuring 30 cm in height were used to prevent participants from running over them, thereby ensuring a proper turn was executed. The trial with the best performance, recorded to the nearest 0.01 s, was retained for subsequent statistical analysis.

2.4. Statistical Analysis

Data are reported as mean ± standard deviation (SD). The Shapiro–Wilk test was employed to assess the assumption of normality. Comparisons were conducted using a 3 × 2 factorial ANOVA with Bonferroni-adjusted post hoc tests using one between-group factor (Pre-PHV vs. Mid-PHV vs. Post-PHV) and one within-group factor (pre- and post-training). Statistical significance was established at $p < 0.05$. Statistical analyses were performed using the SPSS software (version 2022; Chicago, IL, USA). Effect sizes (ES) were calculated from the pre-post changes, and thresholds for Cohen's d were interpreted as trivial (0.00–0.19), small (0.20–0.59), moderate (0.60–1.10), large (1.20–1.90), and very large (>2.00) [44].

3. Results

3.1. Within-Group Analysis

The results of the within-group analysis considering the players' maturation status are shown in Table 2. The analysis revealed that the Pre-PHV group showed a significant improvement in the 10 m ($p = 0.01$; moderate ES) and 30 m ($p < 0.05$; small ES) sprint test, but no changes were observed in any of the other parameters after the intervention ($p > 0.05$). The Mid-PHV group did not report any changes in any of the parameters evaluated ($p > 0.05$), except for the CODAT, where a significant improvement was observed ($p < 0.01$; small ES). The Post-PHV group showed improvements in the CODAT time ($p < 0.05$, small ES) and NHE ($p < 0.05$, small ES), but a significant deterioration in the sprint times for both 10 and 30 m ($p < 0.01$; moderate ES).

Table 2. Changes in different performance variables after the training intervention (mean ± SD).

	Variables	Pre Intervention	Post Intervention	Change Mean (%)	*ES (95%CI)*	*p* Value
Pre-PHV Group	CMJ (cm)	34.0 ± 3.4	34.1 ± 3.4	0.3 ± 8.5	0.03 ± 0.74	0.93
	NHEes (N)	197.9 ± 28.6	188.2 ± 22.2	−4.6 ± 6.2	−0.30 ± 0.38	0.11
	Sprint 10 m (s)	1.96 ± 0.06	1.91 ± 0.05	−2.8 ± 2.0	−0.87 ± 0.62	0.01
	Sprint 30 m (s)	4.79 ± 0.15	4.70 ± 0.16	−2.0 ± 1.5	−0.54 ± 0.40	0.02
	CODAT	5.99 ± 0.27	5.94 ± 0.30	−0.9 ± 3.3	−0.16 ± 0.61	0.54
Mid-PHV Group	CMJ (cm)	36.2 ± 4.2	36.2 ± 5.6	−0.5 ± 5.8	0.00 ± 0.41	0.99
	NHEes (N)	257.6 ± 50.5	260.3 ± 47.8	1.4 ± 3.9	0.05 ± 0.17	0.54
	Sprint 10 m (s)	1.86 ± 0.08	1.85 ± 0.04	−0.8 ± 2.3	−0.18 ± 0.50	0.44
	Sprint 30 m (s)	4.46 ± 0.23	4.41 ± 0.16	−1.2 ± 2.2	−0.22 ± 0.39	0.25
	CODAT	5.87 ± 0.23	5.77 ± 0.18	−1.6 ± 1.2	−0.39 ± 0.28	0.01
Post-PHV Group	CMJ (cm)	38.0 ± 4.1	38.6 ± 4.3	1.5 ± 3.6	0.13 ± 0.30	0.36
	NHEes (N)	290.6 ± 37.3	303.9 ± 32.7	4.9 ± 5.2	0.33 ± 0.32	0.05
	Sprint 10 m (s)	1.78 ± 0.06	1.82 ± 0.05	2.5 ± 1.5	0.63 ± 0.38	0.00
	Sprint 30 m (s)	4.26 ± 0.13	4.35 ± 0.13	2.0 ± 1.2	0.59 ± 0.35	0.00
	CODAT	5.67 ± 0.17	5.61 ± 0.19	−1.4 ± 1.5	−0.43 ± 0.43	0.05

ES: effect size; CMJ: counter movement jump; NHEes: eccentric strength during Nordic hamstrings exercise; CODAT: Change of Direction and Acceleration Test.

3.2. Between-Group Analysis

The results of the between-group comparison are shown in Table 3. The Pre-PHV group did not report any differences compared to the Mid-PHV group in any of the studied variables ($p > 0.05$). However, when the Pre-PHV group was compared to the Post-PHV group, differences were observed in several parameters. The Post-PHV group showed greater improvements than the Pre-PHV group in eccentric hamstring strength ($p < 0.01$; small ES), while the Pre-PHV group showed significant positive changes in sprint times in comparison with the Post-PHV group ($p < 0.01$; moderate and small ES, respectively). Similarly, the Mid-PHV group showed positive changes in sprint times compared with the Post-PHV group ($p = 0.02$; moderate ES for 10 m and $p = 0.01$; moderate ES for 30-m).

Table 3. Comparison of performance variables after training protocol across groups (mean ± SD).

	Variables	Difference in Means	95% CI [LB, UB]	*p* Value
Pre-PHV vs. Mid-PHV	CMJ (cm)	−0.1	[−3.3, 3.0]	0.93
	NHEes (N)	12.3	[−1.9, 26.5]	0.09
	Sprint 10 m (s)	0.0	[0.0, 0.1]	0.13
	Sprint 30 m (s)	0.0	[−0.1, 0.2]	0.49
	CODAT	0.0	[−0.2, 0.1]	0.58
Pre-PHV vs. Post-PHV	CMJ (cm)	0.5	[−2.5, 3.4]	0.74
	NHEes (N)	23.0	[6.4, 39.6]	0.01
	Sprint 10 m (s)	0.1	[0.1, 0.1]	0.00
	Sprint 30 m (s)	0.2	[0.1, 0.3]	0.00
	CODAT	0.0	[−0.2, 0.2]	0.74
Mid-PHV vs. Post-PHV	CMJ (cm)	0.6	[−1.6, 2.8]	0.58
	NHEes (N)	10.7	[−4.3, 25.7]	0.15
	Sprint 10 m (s)	0.1	[0.0, 0.1]	0.02
	Sprint 30 m (s)	0.1	[0.0, 0.2]	0.01
	CODAT	0.0	[−0.1, 0.1]	0.71

LB: lower bound; UB: upper bound; CMJ: counter movement jump; NHEes: eccentric strength during Nordic hamstrings exercise; CODAT: Change of Direction and Acceleration Test.

4. Discussion

The objective of this study was to investigate the adaptations induced by a 7-week training protocol combining strength and power training with regular soccer training in young elite soccer players, considering their maturity level. The results demonstrated that, depending on the level of maturation, the proposed training program appeared to lead to specific adaptations in each group. The Pre-PHV group exhibited improvements in sprinting, while the Mid-PHV and Post-PHV groups showed enhancements in the ability to change direction. Additionally, the Post-PHV group also displayed improvements in the NHE, alongside a decline in sprinting performance. Furthermore, the magnitude of the improvements varied between groups at the end of the training period. Specifically, the Pre- and Mid-PHV groups showed greater improvements in the 10- and 30 m sprint tests compared to the Post-PHV group, whereas the Post-PHV group demonstrated greater enhancements in NHE compared to the Pre-PHV group.

The results of this study showed that improvements in NHE were observed exclusively in the Post-PHV group, which exhibited a significant improvement in NHE compared to the Pre-PHV group. These findings are consistent with the previous literature, which suggests that resistance training is more effective in enhancing strength after the growth peak [19], although, without a control group, natural maturation effects cannot be completely ruled out. The exclusive increase in hamstring strength observed in the Post-PHV group may be attributed to the elevated levels of circulating hormones in players at this stage of

maturation compared to their younger counterparts [23]. These hormonal changes are likely to contribute to greater hypertrophy of the biceps femoris, a muscle previously associated with enhanced eccentric strength in the knee flexors [45]. However, this interpretation remains speculative, as hormonal concentrations were not assessed in this study. When comparing the results of the current study with those of previous research, it is evident that the improvement in NHE in our study (4.9%) was lower than the improvements reported in other studies (10–19%) [46,47]. The discrepancy may be explained by the fact that in the aforementioned studies, the Nordic hamstring exercise was not only used as a test to assess eccentric hamstring strength but also as a training exercise. According to the principle of training specificity, this likely resulted in greater improvements [48]. In contrast, the Nordic hamstring exercise in this study was used exclusively to evaluate eccentric hamstring strength, while several multi-planar exercises with different characteristics were prioritized to improve overall soccer performance. Additionally, when comparing the baseline strength level of our participants (Pre-PHV: 5.06 N/kg) with those in other studies that observed improvements during short training protocols (e.g., Drury et al. [47]: 4.27 N/kg), it is apparent that our participants had higher baseline strength levels. This may have made it more challenging to observe significant improvements and suggests that higher volumes or intensities of strength training may be necessary for participants with higher initial strength levels. Notably, Drury et al. [47] also reported substantial improvements in NHE after just 6 weeks of training.

Despite the improvement in NHE observed in the Post-PHV group, this group reported an increase in sprint times after the intervention period. These results are consistent with the previous literature, which has shown a lack of correlation between eccentric hamstring strength (using NHE) and sprint performance [49]. Likewise, previous authors have indicated that improvements in eccentric hamstring strength, even when combined with plyometric exercises, do not necessarily correlate with improved sprint performance [50]. In contrast, it appears that incorporating exercises that require force production and hip extension in the horizontal plane (e.g., hip thrust) may be closely linked to improvements in sprint performance [19,51,52]. It could be hypothesized that including such exercises in the training program, along with emphasizing those exercises that already target hip extension movement (e.g., deadlift), would likely result in better acceleration and sprinting outcomes.

In contrast, the Pre-PHV group demonstrated improvements in sprint performance at both the 10- and 30 m distances, partially confirming the findings of Viru et al. [53] who identified a spurt in speed development occurring before and around PHV. As suggested by Meylan et al. [19], prior to PHV, there is an optimal development of impulsive muscular actions due to the increased fascicle length and accelerated maturation of the central nervous system. A potential factor contributing to the observed differences in adaptations between groups may be the amount of exposure to maximal sprinting efforts. In the absence of a targeted sprinting intervention, the decline in sprint performance observed in the Post-PHV group may be attributed to insufficient sprint training during regular soccer practice. Conversely, the Pre-PHV group may have achieved more exposure volume to top-speed efforts through their routine training, as their lower maximal speed levels likely allowed them to reach peak velocity more frequently. This speculation is based on the findings of Al Haddad et al. [54], which indicated that younger players tend to achieve higher peak speeds relative to their maximal sprinting speed during matches, compared to older players with a greater maximal sprinting speed. Although this previous study primarily focused on chronological age, it is reasonable to hypothesize that similar trends would emerge if participants were categorized based on biological age. A prior study involving young soccer players of a similar age to the Post-PHV group used in this study showed how adding a weekly specific sprint training (six maximal repetitions of 30 m) to a strength

program improved sprint times, which was not the case with strength training alone [55]. Therefore, to achieve improvements in top speed performance, especially after the peak of growth, practitioners should incorporate tasks where higher speeds are stimulated to a greater extent, such as transition games or small-sided games [56–58].

In this study, repeated change of direction ability was assessed using the CODAT, revealing improvements solely in the Mid-PHV and Post-PHV groups, while no such improvements were observed in the Pre-PHV group. However, no significant differences between the groups were observed. Our results partially align with previous studies that showed a relationship between change of direction performance and lower-limb muscle strength in young elite soccer players [59,60]. Specifically, in the Post-PHV group, both CODAT and NHE performance showed improvements, whereas no such improvement in NHE was observed in the Mid-PHV group. This trend was further corroborated by the lack of progress in both the CODAT and NHE results in the Pre-PHV group. These observations may support the hypothesis that the period preceding peak growth is not conducive to enhancing physical skills that depend on high strength levels. The trend observed could be attributed to the nature of the test used in this study. The CODAT incorporates a series of high-intensity actions, including accelerations, decelerations, and changes in direction at varying angles, all of which require considerable strength to eccentrically absorb high-impact forces and a substantial metabolic demand to re-accelerate the body in new directions [61]. It is essential to acknowledge that the ability to change direction is a multifaceted skill influenced by numerous factors. While strength is a key component, the quality of movement also significantly contributes to performance outcomes [62].

The vertical jump test showed no change in performance for any of the groups. This contrasts with several other studies that have analyzed the effects of strength or plyometric training protocols of similar duration, where significant improvements were observed in vertical jump [16,63,64]. One potential explanation for the lack of effectiveness in this study could be a ceiling effect associated with the participants' already high baseline performance levels, as they belonged to an elite academy and had prior exposure to structured strength and power training. Consequently, their potential for short-term improvement may have been limited compared to less-trained populations [65,66], suggesting a lower trainability that would require a higher training stimulus or a longer intervention period to elicit further gains. Another contributing factor may relate to the timing of the strength sessions, which were performed after soccer practice; accumulated fatigue might have reduced the ability to perform resistance exercises with maximal intent or velocity, thereby constraining explosive adaptations. Additionally, although the power sessions included exercises targeting movement speed, the overall program may not have sufficiently emphasized maximal contraction velocity or intent across all sessions, which are key elements for improving high-speed explosive actions [67]. It is also possible that the power sessions required a greater training volume to induce more substantial adaptations specific to explosive performance. Finally, conducting the intervention in the final part of the season may also have influenced the results, as training adaptations tend to be lower during this period due to high accumulated training loads and chronic fatigue [68,69].

Although the findings of this study offer valuable insights, certain limitations should be acknowledged. Most importantly, the absence of a control group, particularly one corresponding to each maturity category (for example, players continuing with regular soccer training only), limits the ability to attribute the observed adaptations exclusively to the intervention. Natural growth, maturation processes, and the regular training load over the 7-week period could also have contributed to the changes observed. Therefore, these results should be interpreted with caution. Future studies should include an appropriate control group to better isolate the specific effects of the intervention and strengthen causal

inferences. Furthermore, conducting the protocol in the final part of the season may have introduced confounding effects due to accumulated fatigue and the high competitive load typical of this period. These factors could have influenced the players' responsiveness to training and limited the magnitude of performance adaptations observed. Future research should therefore consider applying similar interventions at different phases of the competitive calendar to better isolate training effects and understand seasonal variations in trainability. Another limitation of this study is that the intensity of both strength and power training sessions was autoregulated based on each participant's subjective perception of readiness. While this individualized approach is practical and commonly used in applied sport settings, it may have introduced variability in the actual training stimulus, potentially contributing to heterogeneous responses among players. To enhance internal validity and improve precision in future research, more objective monitoring approaches, such as velocity-based training, percentage of one-repetition maximum (%1 RM), or repetitions in reserve, are recommended to better quantify and standardize training load. Moreover, the absence of a cardiopulmonary exercise test (CPET) limits the assessment of aerobic fitness adaptations, which could have provided complementary information on players' physiological responses to the training program. Finally, the relatively small total sample size (n = 35) and uneven distribution across maturity groups, particularly the Pre-PHV group (n = 9), represent another important limitation. This limited and unbalanced sample may have reduced the statistical power of the analyses and increased the likelihood of Type II errors, potentially masking smaller yet meaningful effects between groups. Consequently, non-significant findings should be interpreted with caution. Future research should aim to include larger and more evenly distributed samples to confirm and expand upon the present results, as the homogeneity of the current cohort (elite male youth soccer players) may limit generalizability.

5. Conclusions

Within the limitations of the modest and uneven sample size and the absence of a control group per maturity category, the strength training protocol proposed in this study, which incorporated one strength session and one power session alongside specific soccer training, suggests that adaptations may depend on the participants' maturity level. This protocol proved effective in enhancing eccentric hamstring strength in the Post-PHV group and improving repeated change of direction in both the Mid- and Post-PHV groups, as well as sprint performance in Pre-PHV soccer players. Prior to reaching peak growth, strength training should prioritize coordination and neurological development, as attempts to increase strength during this period are less effective. However, after the PHV, practitioners can capitalize on more favorable conditions for muscle hypertrophy and overall strength development. It is important to note that improvements in strength do not automatically translate to enhanced sprint performance; therefore, it is recommended to incorporate specific sprint training alongside strength workouts focused on explosive movements after the peak growth phase. These results should therefore be interpreted with caution, as the lack of a control group for each maturity category prevents definitive causal conclusions. Future studies should include such control conditions to confirm these preliminary findings.

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