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Running head: Weekly high-frequency plyometric training

Abstract

Purpose: this study aims to investigate the effects of volume-matched plyometric training (PT) with different frequency distributions on physical performance and muscle soreness in adolescent soccer players. ***Methods:*** Thirty-four sub-elite players were allocated into two groups: PLYO-1 (n = 17, age =16.02±0.26 years) underwent one PT session per week, while PLYO-3 (n = 17, age = 15.81±0.37 years) underwent three volume-matched PT sessions per week. The PT program lasted 9-weeks with an initial weekly volume of ~55-foot contacts, increasing by 10% per week. The 7-point Likert scale was employed to assess the perceived muscle soreness before and after each PT session. All players were tested for countermovement horizontal (CMHJ) and vertical (CMVJ) jumps, 10-m sprint and change of direction (COD) performance using the modified 505 test (505mod). ***Results:*** After the 9-week experimental period, both groups exhibited significant improvements in CMHJ distance ($p < 0.001$; $d = -0.55$) and CMVJ variables (jump height and modified reactive strength index, $p < 0.001$; $d = -0.34$ and $d = -0.33$), and 505mod time (COD deficit) ($p < 0.001$, $d = 1.09$). However, no improvements were observed in the 10-m sprint time for PLYO-1 and PLYO-3 ($p > 0.911$, $d = -0.12$). The changes in perceived muscle soreness were significantly lower for PLYO-3 compared with PLYO-1 ($p < 0.001$, $d = 1.04$) throughout the experimental period. ***Conclusions:*** Employing weekly volume-matched PT conducted at different frequencies can help to maintain, or even enhance, jump and COD performance, while differently impacting muscle soreness.

Keywords: football, stretch-shortening cycle, programming, athletic performance, recovery

Introduction

Plyometric training (PT) is a strength training method characterized by the transition from an eccentric (lengthening) to a concentric (shortening) muscle action [1]. During the eccentric phase, muscles store elastic energy, which is reutilised during the concentric phase and translated to the execution of dynamic athletic movements [2]. This process involves neuromuscular adaptations and is central to the stretch-shortening cycle function, promoting neural potentiation and the stretch-reflex response [1]. These adaptations improve neuromuscular efficiency and athletic performance. Studies have demonstrated that PT is effective for enhancing physical performance in youth athletes (aged under 18 years), with significant improvements in jumping, sprinting and change of direction (COD) abilities [3,4] observed in preadolescent [3] and adolescent [11,12] soccer players.

In youth athletes, growth and maturation can further amplify the effects of PT through changes in muscle size, muscle fascicle length, pennation angle, tendon stiffness and motor unit recruitment through various different physiological mechanisms and environmental factors (i.e., other training types) [5,6]. However, despite the potential benefits of PT as a training modality in youth, the high impact-based nature of plyometric type movement imposes significant forces on the trainee of up to seven times bodyweight for specific exercises [7], which, if not properly managed, can jeopardize recovery by leading to potentially negative consequences such as overtraining [8], performance decrements [9], increased training load [10] and augmented injury risk [11]. Proper programming [11,12]~~, as previously emphasized by Ramirez-Campillo et al. [9],~~ is essential to balance the high-intensity demands of PT with adequate recovery, ensuring progression while minimizing fatigue and soreness, as previously emphasized by Ramirez-Campillo et al. [9].

Recent studies have investigated the effects of different PT distributions (i.e., 1 session per week vs. 2 sessions per week) on physical performance in young soccer players [13–16]. Performing 1 or 2 sessions per week provided similar physical performance adaptations in young soccer players, at least in the short term (~8 weeks). Similarly, this applied also for higher frequency distribution (2 sessions per week vs. 4 sessions per week) resulting in comparable physical performance improvements among adolescent soccer players [17]. Notably, distributing plyometric sessions more frequently (>2 sessions per week) appears to optimize weekly training loads and mitigate fatigue [18–20]. Despite these beneficial effects, limited evidence exists on how different ~~training~~ PT distributions can affect athletic performance and muscle soreness in adolescent soccer players. This is a crucial factor for the management of soccer-specific training demands and recovery in youth players. Accordingly, the purpose of this study was to investigate the effects of PT, conducted at different weekly frequencies, on physical performance and muscle soreness in adolescent soccer players. We hypothesized that both PT frequencies (1 session per week vs. 3 sessions per week) would improve physical performance with high weekly training frequency leading to a lower muscle soreness perception, due to a more distributed load of PT.

Methods

Participants

A priori power analysis determined that a pre-to-post parallel design with 16 participants per group (power = 0.95) could detect a medium effect size (0.5) with α = 0.05. Sample size computation accounted for two groups and measurements based on prior research examining changes in jumping performance metrics for a similar purpose [17]. Thirty-four under-16 sub-elite male soccer players from the same academy were recruited and divided into two experimental groups: one underwent PT once per week (PLYO-1, n = 17, age =16.02 ± 0.26 years, height = 1.79 ± 0.06 m, body mass = 67.77 ± 8.84 kg, maturity offset = 1.7 ± 0.4 years) and the other received a total volume-matched PT distributed three times per week (PLYO-3, n = 17, age = 15.81 ± 0.37 years, height = 1.76 ± 0.06 m, body mass = 66.54 ± 7.10 kg, maturity offset = 1.73 ± 0.5 years) for a 9-week training period. Specifically, they were matched based on baseline physical performance, considering all test results, and then randomly assigned to either PLYO-1 or PLYO-3. This ensured initial comparability and reduced selection bias. No control group was included, as PT was already part of the players' soccer training routine [14]. Each participant had a minimum of seven years of soccer training background. Required adherence to the training intervention was set at 85%. All participants who started the intervention completed the study. To be included, players had to train at least four times per week, (1.5 h per session), play one weekly official competition and compete in a league below the professional level for their age group. Exclusion criteria included chronic conditions (e.g., asthma), illnesses (e.g., flu-like conditions), or injuries (e.g., musculoskeletal and osteoarticular disorders). Players and their parents or legal guardians provided a signed informed consent, and the study followed the Helsinki Declaration principles. The study was approved by the Ethical Committee of the local University.

Experimental design

This study used a randomized pre- and post-intervention parallel group design (Figure 1) conducted during the second phase of the 2023/2024 in-season period, from February to May. The participants underwent one or three weekly volume-matched PT sessions for a 9-week period. The sprint, COD, and jump ability assessments were conducted at pre- and post- intervention. A muscle soreness scale was employed to assess the perceived muscle discomfort induced by the PT in each group, for each session.

Insert Figure 1 here

Procedures

A familiarization session was conducted to standardize procedures, even though perceptual and physical performance assessments were part of the players' monitoring routine. Measurements occurred one week before and after the intervention over three days. Anthropometric variables (stature, sitting height and body mass) were recorded on day one using a stadiometer (SECA 213, Germany) and a portable scale (SECA 813, Germany), accurate to 0.1 cm and 0.1 kg, respectively. Maturity offset was estimated using the equation by Mirwald et al. [21]. Sprint and COD tests were conducted on day two of testing and jump tests on day three, both randomized and performed at the same time of day. This order was based on logistical constraints and surface availability. Players wore their usual footwear soccer shoes for outdoor sprint and COD tests on outdoor artificial grass, and sneakers for indoor jump tests.

Perceptual assessments

The Borg category-ratio scale anchored at the number 10 was used to ensure all players experienced the similar rate of perceived exertion (RPE) [22] and training load~~ (session-RPE)~~. The training load was calculated by multiplying RPE by session duration in minute. RPE was collected individually 30 min after each session (Table 2). Muscle soreness was monitored using the~~a~~ 7-point Likert scale [23], where 0 indicates no soreness and 6 indicates soreness that limit~~sing~~ the participants' ability to move. Participants rated their lower-limb soreness before the warm-up and immediately after the intervention in each session (Table 2), ensuring consistent perceptions of soreness without impairing performance [23].

Physical performance assessment

The testing battery encompassed a 10-m sprint test, a modified 505 COD test (505mod), and vertical (CMVJ) and horizontal (CMHJ) jump tests with countermovement. Prior to the athletic assessment, a standardized 5-minute warm-up was conducted based on slow running (forward and backward), acceleration and deceleration exercises, and jumping drills at progressive intensities [24].

10-m sprint test. Each subject performed three maximal 10-m sprints from a standing position, interspersed with 2 min of passive recovery [25]. The best performance time was considered in the analysis. To measure sprinting speed, an electronic timing system based on photocells (WICHRO, Chronojump Boscosystem©, Barcelona, Spain) was used. The photocells were placed at a height of 0.7 m near the start and finish lines. The athletes were positioned 0.3 m away from the start timing gates to prevent an early trigger of the electrical instrumentation due to the leaning trunk.

Modified 505 COD test (505mod). Players performed a 10-m sprint test with a 180-degree turn, sprinting 5 m back to the starting point [26]. Three trials were completed in each direction (left and right) with ~~two minutes~~2 min of passive recovery between them. The best time for each direction was used for the analysis. Total time and COD deficit, calculated by subtracting the 10-m sprint time from the 505mod total time, were the variables analysed. The timing gate system setup was the same as that used for the 10-m sprint test.

Countermovement vertical jump (CMVJ). The CMVJ was evaluated using a force platform (ForceDecks, VALD, Brisbane, Australia) with sampling at 1000 Hz and cut-off filtering at 50 Hz to allow evaluation of force-time characteristics. The force platform was placed on a flat, solid surface and zeroed before giving instructions to participants. Participants were required to stand upright on the platform with their hands on their hips for the time required for body weight acquisition [27]. After that, they were asked to jump as high and as fast as possible. Each participant performed three jumps with a recovery time between 30 s and 60 s, and the best one was incorporated into the analysis. The variables to be evaluated were: i) jump height, derived from the velocity of the centre of mass at the time of take-off, based on the impulse-movement relationship and take-off time; ii) reactive strength index (RSImod) representing the ratio between jump height and contraction time and indicating the efficiency of force generation during ground contact relative to the achieved vertical height; iv) 50 ms and 100 ms concentric impulse for assessing the ability to express force during the concentric phase and the ability to maintain it over time.

Countermovement horizontal Jump (CMHJ). In this test, each participant had to perform a horizontal jump with both feet, starting from a static position with a free use of the arms. The goal was to measure the maximum horizontal distance. The distance was assessed by a measuring tape (accuracy of 0.1 cm) from the starting line to the heel of the furthest back foot at the point of impact on the landing surface. Each participant performed three jumps, and the longest jump was used for analysis.

Training intervention

Both PLYO-1 and PLYO-3 groups completed a 9-week in-season PT intervention with 1 or 3 training sessions per week, respectively, performed after a standardized warm-up at the initial phase of each session. PLYO-1 completed its PT session on ~~a~~ Tuesday while PLYO-3 performed its sessions on Tuesdays, Thursdays and Fridays. All players participated in regular soccer-specific training (technical and tactical drills) on the same days as their PT sessions. Competitive matches were held on Sundays and rest days were scheduled on Mondays and Saturdays. On non-PT days, both groups followed the same soccer-specific training as part of their regular weekly routine (Figure 1). Specifically, on Thursdays and Fridays, the PLYO-1 group engaged in standard soccer training, including technical skills such as ball conduction, passing and receiving. Although different in nature from the PT performed by PLYO-3, the technical drills completed by PLYO-1 likely imposed a comparable neuromuscular load. The PT program (Table 1) included vertical (e.g., drop jumps, tuck jumps) and horizontal (e.g., bilateral forward jumps, lateral zig-zag jumps) jumping exercises with < 15 s recovery between repetitions and > 60 s between sets [15]. The volume began at ~55 foot contacts per week [9] and increased by 10% weekly, reaching ~118 foot contacts per each week, ensuring maximum effort for each jump [9]. Training sessions were supervised (1:4 coach-to-player ratio) to ensure proper demonstration and execution. Each session followed a six-step protocol: I) pre-training muscle soreness evaluation; II) warm-up; III) PT or soccer training; IV) post-intervention evaluation of muscle soreness; V) soccer training; VI) post-session RPE and training load computation (RPE × session duration) (Table 2).

Statistical Analyses

Data normality was verified by the Shapiro-Wilk's test. Relative reliability was assessed with the intraclass correlation coefficient (ICC, model 3,k), interpreted as poor (< 0.50), moderate (0.5-0.74), good (0.75-0.90) and excellent (> 0.90) [28]. Absolute reliability was evaluated using the coefficient of variation (CV = [standard deviation/mean)] × 100). After verifying the homogeneity of variance by the Levene's test, a two-way repeated measures analysis of variance was conducted to analyze potential interactions between PLYO-3 and PLYO-1 on perceptual and physical performance after 9 weeks. Bonferroni's post-hoc test was applied for multiple comparisons. Cohen's *d* (*d*) effect size quantified the magnituted of the simple and main effects. The magnitude thresholds were as follows: $d < 0.2$ negligible, $d < 0.5$ small, $d < 0.8$ medium, and $d \geq 0.8$ large [29]. Confidence intervals (95%) were provided. To assess the practical significance of performance changes by PLYO-1 and PLYO-3, the small worthwhile change (SWC) was computed as 0.2 × between-subject standard deviation from baseline measures. All analyses were performed using GraphPad Prism software (GraphPad Software v.8.0.2, San Diego, USA).

Results

Table 3 showed good to excellent reliability data and sensitivity values for physical performance. The SWC values are also reported indicating a practical significant in all performance outcomes (Table 3). A significant main effect of time ($F_{(4,136)}$= 5.029, p < 0.001) was observed for the delta score of muscle soreness (Figure 2), with week 9 differing significantly from week 3 (p < 0.001, *d* = 0.89 [0.16 to 1.62]), week 5 (p < 0.01, *d* = 0.70 [−0.006 to 1.42]), and week 7 (p = 0.041, *d* = 0.64 [−0.06 to 1.35]). Moreover, muscle soreness was significantly higher in PLYO-1 compared with PLYO-3 ($F_{(1,32)}$= 144.3, p < 0.001, *d* = 1.04 [0.30 to 1.78]). No significant interaction was detected between groups ($F_{(4, 136)}$ = 0.59, p = 0.663, *d* = 0.25 [−0.44 to 0.95]). Across all sessions, ~~session RPE~~training load values for PLYO-1 and PLYO-3 were comparable (ranging from 241 ± 25 a.u. to 349 ± 36 a.u.), showing negligible to small effect sizes (from $0.04 \leq d \leq 0.24$).

Insert Figure 2 here

In the 10-m sprint test, neither significant effect of time ($F_{(1, 32)}$ = 0.01, p = 0.911, *d* = −0.12 [−0.81 to 0.57]) nor effect of group ($F_{(1, 32)}$ = 0.24, p = 0.62, *d* = 0.04 [−0.64 to 0.73]) nor significant interaction ($F_{(1, 32)}$ = 0.61, p = 0.436, *d* = −0.09 [−0.78 to 0.60]) were found (Figure 3~~5~~; Panel A). For 505mod performance (Figure 3~~5~~, Panel B), a significant main effect of time ($F_{(1, 32)}$ = 22.96, p < 0.001, *d* = 1.09 [0.35 to 1.84]), although neither significant interaction ($F_{(1, 32)}$ = 2.70, p = 0.110, *d* = −0.54 [−1.24 to 0.16]) nor significant effect of group ($F_{(1, 32)}$ = 3.28, p = 0.08, *d* = −0.23 [−0.93 to 0.46]) were revealed. For CMHJ performance (Figure 4~~3~~), a significant main effect of time ($F_{(1,32)}$= 27.28, p < 0.001, *d* = −0.55 [−1.25 to 0.15]) was observed, but neither interaction ($F_{(1, 32)}$ = 1.18, p = 0.285, *d* = −0.23 [−0.71 to 0.25]) nor group effect ($F_{(1, 32)}$ = 0.93, p = 0.34, *d* = −0.30 [−1.00 to 0.38]) were found. Similarly, CMVJ height showed a significant main effect of time ($F_{(1, 32)}$ = 16.91, p < 0.001, *d* = −0.34 [−1.04 to 0.35]), but neither significant interaction ($F_{(1, 32)}$ = 0.83, p = 0.368, *d* = −0.17 [−0.65 to 0.31]) nor group effect ($F_{(1, 32)}$ = 0.52, p = 0.47, *d* = 0.00 [−0.69 to 0.69]) were found (Figure 5~~4~~, Panel A). In the RSImod performance, neither significant interaction ($F_{(1, 32)}$ = 0.92, p = 0.344, *d* = −0.29 [−0.77 to 0.19]) nor significant effect of group ($F_{(1, 32)}$ = 0.34, p = 0.56, *d* = −0.10 [−0.80 to 0.58]) were found, while it was observed a significant main effect of time ($F_{(1, 32)}$ = 5.45, p = 0.026, *d* = −0.33 [−1.02 to 0.36]) (Figure 4~~5~~, Panel B). In the 50 ms concentric impulse, PLYO-1 improved by 2.39% (pre, 48.06 N·s ± 16.71 N·s; post, 49.21 N·s ± 15.32 N·s) and PLYO-3 by 6.84% (pre, 49.36 N·s ± 8.59 N·s; post, 52.73 N·s ± 9.21 N·s), but neither significant effect of time ($F_{(1, 32)}$ = 1.02, p = 0.319, *d* = −0.17 [−0.86 to 0.52]), nor effect of group ($F_{(1, 32)}$ = 0.40, p = 0.52, *d* = −0.19

[−0.88 to 0.50]) nor interaction ($F_{(1, 32)}$ = 0.24, p = 0.622, *d* = −0.17 [−0.65 to 0.31]). Parallelly, for 100 ms concentric impulse, improvements were 2.79% (pre, 93.43 N·s ± 30.88 N·s; post, 96.04 N·s ± 28.26 N·s) in PLYO-1 and 5.16% (pre, 94.28 N·s ± 14.41 N·s; post, 99.14 N·s ± 16.15 N·s) in PLYO-3, again with neither effect of time ($F_{(1, 30)}$ = 0.79, p = 0.379, *d* = −0.16 [−0.86 to 0.52]) nor group effect ($F_{(1, 32)}$ = 0.08, p = 0.77, *d* = −0.01 [−0.78 to 0.59]) nor interaction ($F_{(1, 32)}$ = 0.07, p = 0.789, *d* = −0.09 [−0.57 to 0.38]). ~~In the 10-m sprint test, neither significant effect of time ($F_{(1, 32)}$ = 0.01, p = 0.911, *d* = −0.12 [−0.81 to 0.57]) nor effect of group ($F_{(1, 32)}$ = 0.24, p = 0.62, *d* = 0.04 [−0.64 to 0.73]) nor significant interaction ($F_{(1, 32)}$ = 0.61, p = 0.436, *d* = −0.09 [−0.78 to 0.60]) were found (Figure 5; Panel A). For 505mod performance (Figure 5, Panel B), a significant main effect of time ($F_{(1, 32)}$ = 22.96, p < 0.001, *d* = 1.09 [0.35 to 1.84]), although neither significant interaction ($F_{(1, 32)}$ = 2.70, p = 0.110, *d* = −0.54 [−1.24 to 0.16]) nor significant effect of group ($F_{(1, 32)}$ = 3.28, p = 0.08, *d* = −0.23 [−0.93 to 0.46]) were revealed.~~

Insert Figure 3 here

Insert Figure 4 here

Insert Figure 5 here

Discussion

This study examined the effects of volume-matched PT interventions conducted at different frequencies on physical performance and muscle soreness in adolescent soccer players. The main findings indicated that the 9-week PT program significantly improved CMHJ, CMVJ, and 505mod performance in both training frequency groups (PLYO-3 and PLYO-1), with effect sizes ranging from small to large. The absence of significant interaction and group effects with negligible to small effect sizes suggest that both approaches produced comparable outcomes. However, the perceived increase in muscle soreness was significantly lower in PLYO-3 compared to PLYO-1 with a large effect size being demonstrated. These results confirm our initial hypothesis that both PT frequencies enhance physical performance while resulting in different levels of muscle soreness and, by extension, a potentially optimal spreading of workloads across the training week for the PLYO-3 group. Overall, this study contributes to the existing literature by comparing different weekly frequencies of volume-matched PT in adolescent soccer players, suggesting that a higher training frequency may reduce perceptions of muscle soreness without compromising physical performance.

Previous studies found that low-frequency PT (< 3 sessions per week) can also enhance physical performance [13–16] in young soccer players. For example, Bouguezzi et al. [13] found that one session vs. two sessions per week were equally effective in improving sprint, COD, and jumping performance (vertical and horizontal jump height and RSImod) in preadolescent male soccer players. In that study, the weekly jump volume was matched between groups with a progression from ~50 to ~~120 foot~~120 foot contacts over the course of the study. Similarly, Ramirez-Campillo et al. [15] observed similar improvements in young adult female soccer players with comparable weekly training distributions. Likewise, the training volume was matched between groups ranging from 80 to ~~140 foot~~140 foot contacts per week. Consistent with these findings (except for sprint performance), our volume-matched plyometric intervention (55 ~~-~~to 118 foot contacts per week) also led to improvements in COD (COD deficit), vertical and horizontal jump performance (e.g., jump height, distance, and RSImod) regardless of training frequency. Furthermore, dividing weekly training volumes into more frequent, shorter sessions appears to reduce neuromuscular fatigue and improve recovery as evidenced by lower RPE values in volume-matched high-frequency strength training protocols [18,20]. This strategy is particularly useful for optimizing adaptations to plyometric stimuli [19] during congested training and match periods. Supporting this, Liu et al. [17] found that both protocols of four sessions per week and two sessions per week of PT led to improvements in SJ and CMJ height, drop jump RSI, and 10-m sprint time in under-17 soccer players [17]. However, training volume was not matched, as with the micro-dosed group performed 41 foot41 foot contacts per week while the regular-frequency group performed 82 foot contacts per week. Despite this limitation, Tthese findings, alongside the current study, confirm the efficacy of higher-frequency PT in improving performance outcomes infor adolescent soccer players.

In addition to the above, our study offers novel insights by showing that varying the distribution of volume-matched PT can lead to different levels of perceived muscle soreness as observed in the PLYO-3 group as compared withagainst PLYO-1. In PLYO-3 and PLYO-1, the perceived muscle soreness, assessed before and immediately after each PT sessionsintervention increased over the experimental period, with the highest delta score values observed during the final week of the program. This result was expected, as the 10% weekly incremental increase in foot contacts resulted in progressively higher workloads as the study proceeded. To mitigate the risk of injuries, Bedoya et al. [11] previously recommended an initial volume ~50–60 foot contacts/session, progressively increasing to no more than 80-120 foot contacts/session for youth soccer players. Our study adhered to this recommendation in PLYO-1. However, in PLYO-3, the initial number of foot contacts/session was lower than previously reported [10,11]. By the final weeks, foot contacts per session in PLYO-3 matched the recommended values, while the total weekly volume of contacts remained identical between the two groups over the 9-week program.

Previous studies have highlighted the role of PT in improving both horizontal and vertical jump performance in youth athletes [30]. In the current study, the observed changes in RSImod confirm the effectiveness of PT in enhancing the rapid force production required for dynamic soccer-specific actions such as jumps, CODs and sprints [13]. Additionally, the reported slight increases in the 50 ms and 100 ms concentric impulse observed could also emphasize enhanced force application during the early phase of movement [1], potentially contributing to faster, more dynamic movement on the field of play. However, these improvements were associated with a small effect size, limiting the extent to which definitive conclusions can be drawn. Collectively. these findings suggest that different PT distributions not only improve overall performance but also provide adaptations aligned with the soccer-specific physical demands (i.e. as jumps, CODs and sprints)[4].

Our findings on COD performance align with previous studies using COD deficit [4,31] as an outcome measure, which can isolate COD ability from sprinting performance. Nobari et al. [31], reported improvements in COD deficit with both horizontal and vertical PT in semi-professional players, while Söyler et al. [4] observed similar improvements following a greater distribution of PT in elite adolescent soccer players. Overall, these results are consistent with the existing literature [32][40], suggesting that between six and nine weeks of PT, with 12–18 sessions and 60–200 contacts per session, appear sufficient to improve COD ability in soccer players. Our findings further support the importance of higher PT frequencies in enhancing COD ability.

In contrast to the aforementioned results, neither the PLYO-1 nor the PLYO-3 groups showed improvements in 10-m sprint time following the 9-week PT protocol. Evidence suggests that enhancing sprint performance requires training programs incorporating sprint-specific exercises [33]. Additionally, for adolescent athletes, combining strength training and PT has been shown to be more effective in improving sprint performance than relying solely on PT [34].

The present study is not without limitations. The use of a randomized parallel group design might have introduced variability to the interpretation of muscle soreness across different subjects. A cross-over design would have allowed for controlling such individual differences, leading to more accurate interpretations of changes in muscle soreness in response to the intervention. Secondly, the inclusion of sub-elite soccer players might limit the generalization of our findings to elite peers, as differences in training intensity and background could influence their response to PT. Thirdly, while PLYO-3 completed PT, PLYO-1 performed technical drills on Thursdays and Fridays. Although these drills likely provided a comparable neuromuscular load, the difference in training content represents a potential confounding factor that should be considered.

Practical Applications

A high-frequency PT regimen (3 sessions per week) can be particularly beneficial to optimize weekly load distribution and manage muscle soreness in youth soccer. This approach allows young players to maintain or enhance strength and power while also balancing the often-substantial workloads associated with soccer training and match play, particularly during the in-season period of the calendar year. Incorporating PT exercises with a progressive 10% increase in weekly foot contacts can improve horizontal and vertical jump capacity, COD performance, and overall athletic readiness.

Conclusions

The results of the current study indicate that when PT is applied in volume-matched protocols at different frequencies, it can effectively enhance jump and COD performance but not sprint performance in adolescent soccer players. Furthermore, three sessions per week of PT resulted in lower increase in perceptions of muscle soreness compared with one session per week. Future research should investigate the effects of higher frequency. microdosed PT (e.g., 4 vs. 2 sessions per week) on physical performance and muscle soreness perception.

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Figure 1. A schematic representation of the experimental design. Pre-testing and post-testing sessions were performed one week before and after the 9-week intervention period. PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three volume-matched PT sessions per week.
Note: M = Monday (rest day for both groups); T = Tuesday (PT session 1 for PLYO-1 and PLYO-3); W = Wednesday (same sport-specific session for both groups); T = Thursday (PT session 2 for PLYO-3); F = Friday (PT session 3 for PLYO-3); S = Saturday (rest day for both groups); S = Sunday (match day for both groups).

Figure 2. Changes of delta score (post-pre) values in muscle soreness by the 7-Point Likert Scale over the 9-week experimental period.
Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week; u.a. = arbitrary units. # Significant ($p < 0.05$) main effect of time; post-hoc comparisons for main effect of time: lower case letters indicate significant difference in week 9 compared with week 3 (*a*), week 5 (*b*), week 7 (*c*), respectively. * Significant ($p < 0.05$) difference for the main effect of group.

Figure 43. Individual pre and post values of the countermovement horizontal jump (CMHJ) test.
Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week. ### Significant ($p < 0.001$) main effect of time.

Figure 54. Individual pre and post values of the countermovement vertical jump (CMVJ) test. Panel A and Panel B show the individual jump height and the modified reactive strength index (RSImod) performance, respectively.
Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week. # Significant ($p < 0.05$) main effect of time; ### Significant ($p < 0.001$) main effect of time.

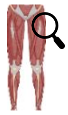
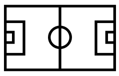
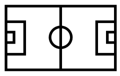
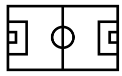
Figure 35. Individual pre and post values of the 10-m sprint and change of direction tests. Panel A and Panel B show the individual sprint time and change of direction deficit (COD deficit) performance, respectively.
Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week. ### Significant ($p < 0.001$) main effect of time.

Table 1. Characteristics of the plyometric training programs.

Intervention	N. of Weeks	Session	FCT	Exercise								
				Bilateral forward jump (rebound)	Drop jump + two-foot vertical bounce	Forward side jumps (zig-zag 45°)	Hurdle jumps	Alternate side jumps + bounce	Drop jump + two-foot forward bounce	Tuck jump (rebound)	Two-foot jumps on "square path"	Drop jump + two-foot side bounce
PLYO-1	**Week 1**	**S1**	~55	1 × 5	1 × 6	2 × 4	1 × 5	2 × 4	1 × 6	1 × 5	2 × 4	1 × 4
	Week 9		~118	2 × 8	2 × 6	3 × 4	2 × 8	3 × 4	2 × 6	2 × 7	2 × 8	2 × 4
PLYO-3	**Week 1**	**S1**	~19	1 × 5	1 × 6	2 × 4						
		S2	~19				1 × 5	2 × 4	1 × 6			
		S3	~17							1 × 5	2 × 4	1 × 4
	Week 9	**S1**	~40	2 × 8	2 × 6	3 × 4						
		S2	~40				2 × 8	3 × 4	2 × 6			
		S3	~38							2 × 7	2 × 8	2 × 4

Note: PLYO-1 = experimental group receiving one plyometric training session per week; PLYO-3 = experimental group receiving three plyometric training sessions per week. FCT = ground foot contact. Exercises were performed with the intent to jump at maximum intensity. The number of FCT increased by 10% each week, from ~55 (week 1) to ~118 (week 9).

Table 2. Experimental approach and training protocol.

Intervention	Session 1		Session 2		Session 3	
	PLYO-1	PLYO-3	PLYO-1	PLYO-3	PLYO-1	PLYO-3
I						
II						
III						
IV						
V						
VI	RPE (training load)		RPE (training load)		RPE (training load)	

Note: PLYO-1 = experimental group receiving one plyometric training session per week; PLYO-3 = experimental group receiving three plyometric training sessions per week; RPE = Rate of Perceived Exertion. Within the training sessions, the experimental protocol consisted in six steps: I) muscle soreness evaluation; II) warm-up protocol; III) plyometric/soccer training; IV) muscle soreness evaluation V) soccer training VI) Rate of Perceived Exertion evaluation.

Variables		ICC (95% CI)	CV%	SWC
10-m sprint				
	Running time (s)	0.869 [0.756 to 0.932]	1.5	0.021
505mod				
	COD deficit (s)	0.822 [0.67 to 0.908]	1.6	0.019
CMHJ				
	Distance (cm)	0.974 [0.949 to 0.987]	1.1	3.215
CMVJ				
	Jump height (cm)	0.966 [0.931 to 0.981]	2.4	1.025
	RSImod (m/s)	0.947 [0.896 to 0.976]	4.3	0.017
	50 ms concentric impulse (N·s)	0.948 [0.897 to 0.977]	5.6	2.306
	100 ms concentric impulse (N·s)	0.957 [0.914 to 0.981]	5.3	4.184

Note: Values are reported with two or three decimal places depending on the level of precision required. ICC = intraclass correlation coefficient; 95% CI = coefficient interval at 95%; CV = coefficient of variation; SWC = smallest worthwhile change. 505mod = modified 505 change of direction test; COD deficit = change of direction deficit; CMHJ = countermovement horizontal jump; CMVJ = countermovement vertical jump; RSImod = modified reactive strength index.

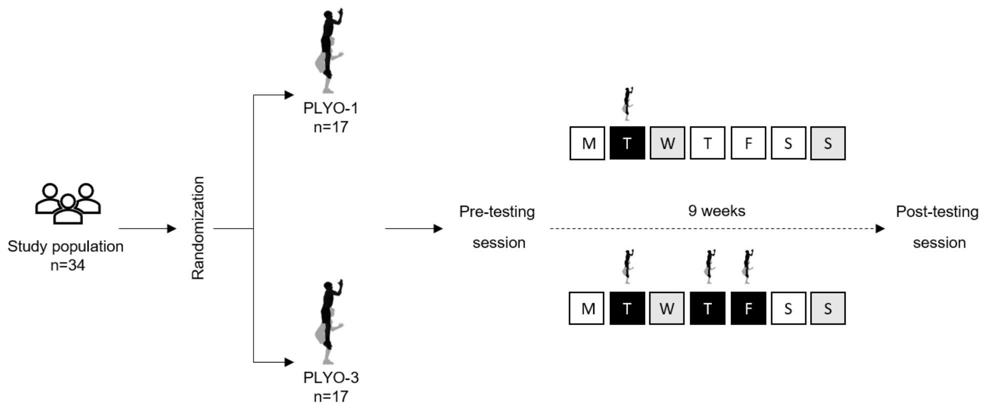


Figure 1. A schematic representation of the experimental design. Pre-testing and post-testing sessions were performed one week before and after the 9-week intervention period. PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three volume-matched PT sessions per week.
Note: M = Monday (rest day for both groups); T = Tuesday (PT session 1 for PLYO-1 and PLYO-3); W = Wednesday (same sport-specific session for both groups); T = Thursday (PT session 2 for PLYO-3); F = Friday (PT session 3 for PLYO-3); S = Saturday (rest day for both groups); S = Sunday (match day for both groups).

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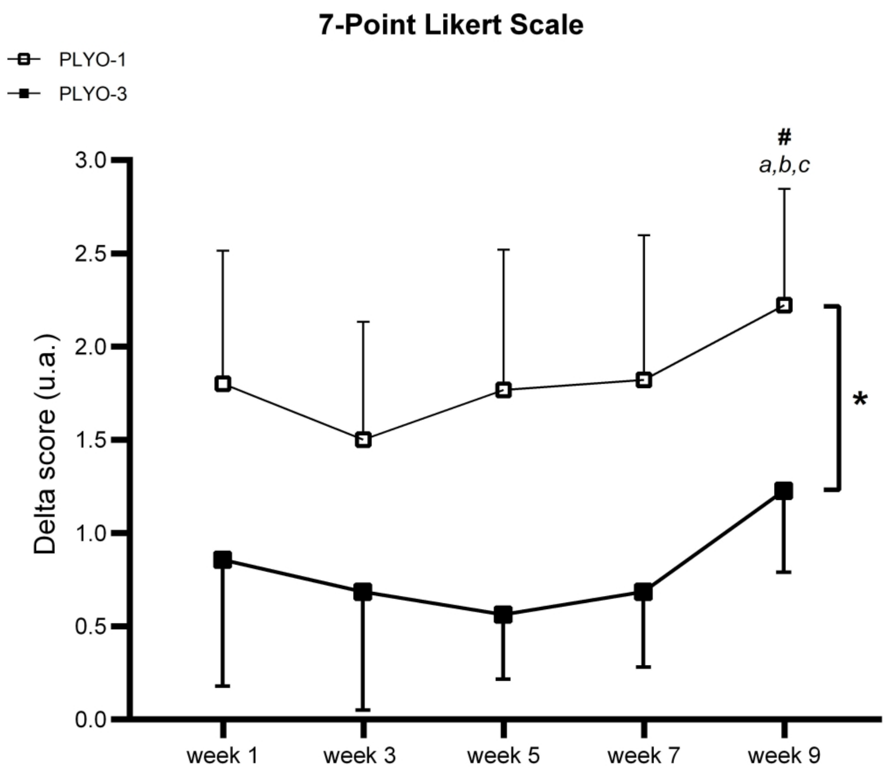

Figure 2. Changes of delta score (post-pre) values in muscle soreness by the 7-Point Likert Scale over the 9-week experimental period.
Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week; u.a. = arbitrary units. # Significant ($p < 0.05$) main effect of time; post-hoc comparisons for main effect of time: lower case letters indicate significant difference in week 9 compared with week 3 (a), week 5 (b), week 7 (c), respectively. * Significant ($p < 0.05$) difference for the main effect of group.

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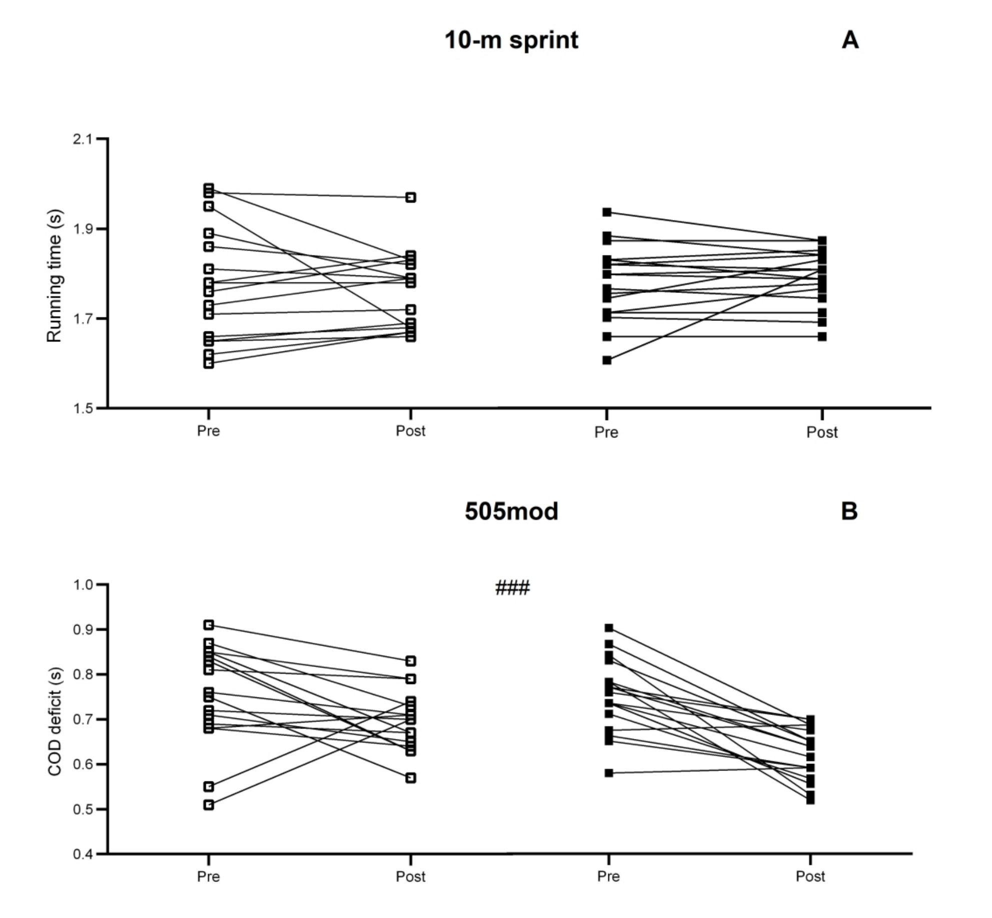

Figure 3. Individual pre and post values of the 10-m sprint and change of direction tests. Panel A and Panel B show the individual sprint time and change of direction deficit (COD deficit) performance, respectively. Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week. ### Significant ($p < 0.001$) main effect of time.

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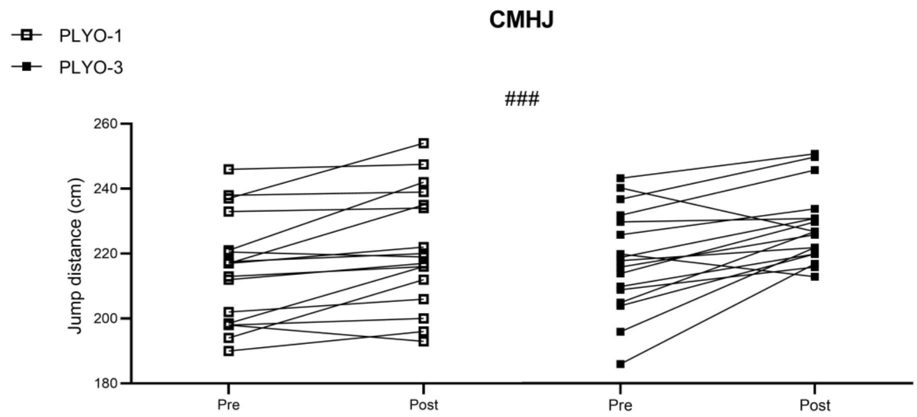

Figure 4. Individual pre and post values of the countermovement horizontal jump (CMHJ) test. Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week. ### Significant ($p < 0.001$) main effect of time.

902x419mm (118 x 118 DPI)

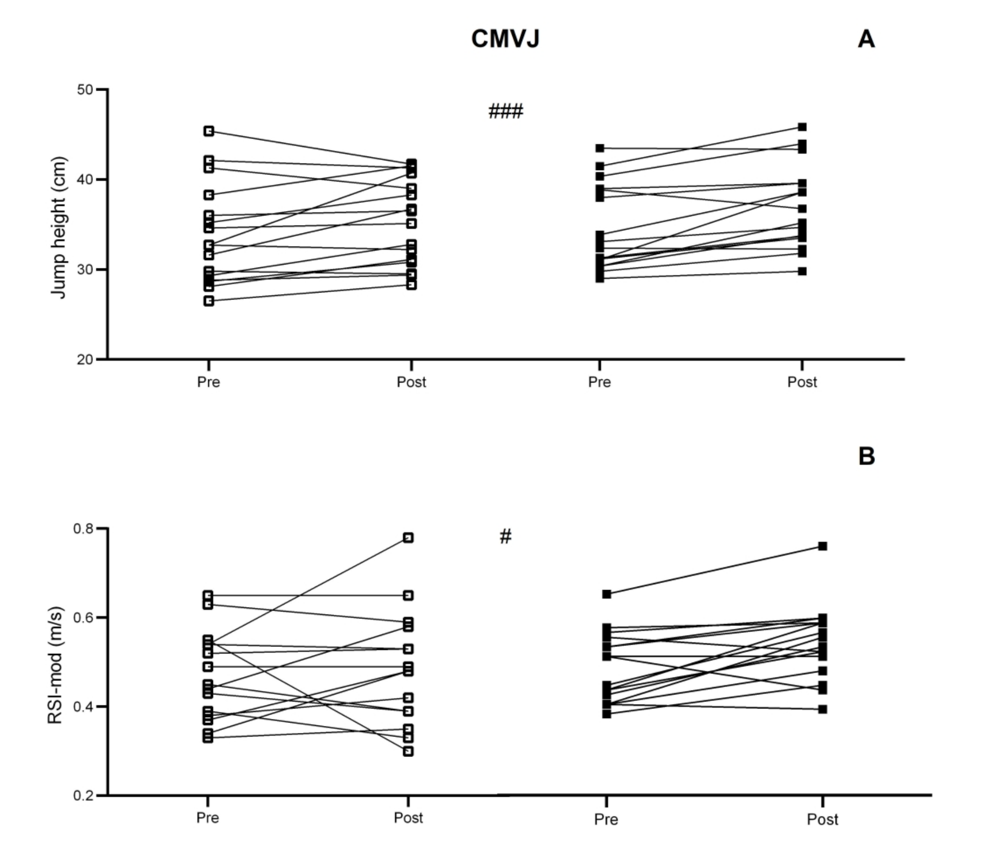

Figure 5. Individual pre and post values of the countermovement vertical jump (CMVJ) test. Panel A and Panel B show the individual jump height and the modified reactive strength index (RSImod) performance, respectively. Note: PLYO-1 = experimental group receiving one PT session per week; PLYO-3 = experimental group receiving three matched-volume PT sessions per week. # Significant ($p < 0.05$) main effect of time; ### Significant ($p < 0.001$) main effect of time.

860x749mm (118 x 118 DPI)