Effects of plyometric jump training versus power training using free weights on measures of physical fitness in youth male soccer players

Running title: Effects of plyometric vs. power training on physical fitness in youth athletes

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Abstract

This study aimed to contrast the effects of power training (PT), using free-weights, and plyometric-jump-training (PJT) programs on measures of physical fitness in pre-peak height velocity (pre-PHV) male soccer players. Thirty-three participants were randomly allocated to PT group (n=11; age = 12.8±0.2 years), PJT group (n=11; age=12.7±0.3 years), and an active control group (CG; n=11; age=12.8±0.3 years). Before and after 12 weeks of training, tests were performed for the assessment of sprint-speed (5m, 10m, 20m, and 30m), change-of-direction (CoD) speed, muscular strength (half-squat one-repetition maximum [1RM]), and aerobic-endurance (AE). Findings indicated significant group×time interaction effects for all sprint-speed intervals, CoD speed, AE, and strength (d=0.20-0.32;$p<0.05$;). Post-hoc analyses revealed moderate-to-large improvements in all sprint-speed intervals, CoD speed, AE, and muscle strength following PT (ES=0.71 to 1.38; $p<0.05$). The PJT induced moderate-to-large enhancements in 10m, 20m, and 30m sprint, CoD speed, and AE (ES=0.51 to 0.96;$p<0.05$) with no significant changes for 5m sprint-speed and muscle strength (ES=0.71 and 0.16; $p>0.05$, respectively). No significant pre-post changes were observed for the CG ($p>0.05$). Overall, PT and PJT are effective means to improve various measures of physical fitness in pre-PHV male soccer players. Notably, to additionally improve acceleration and muscle strength, free-weights PT has an advantage over PJT.

Key words: resistance training; stretch-shortening cycle; athletic performance; youth athletes; football.

Introduction

Soccer is characterized by an alternation of high- and low-intensity activities such as sprinting, change of direction (CoD) speed, jogging, and standing (Stølen, Chamari, Castagna, & Wisløff, 2005). Specifically, high-intensity actions (e.g., sprinting, jumping, CoD speed) largely influences soccer match performance in young players (Wisløff, Helgerud, & Hoff, 1998). Indeed, the ability to repeatedly perform high-intensity actions requires a high level of aerobic endurance (AE) (Impellizzeri et al., 2006). It has been demonstrated that improved AE increases total distance covered, play intensity, the number of sprints performed, and ball involvement during matches in elite players aged 18 years (Helgerud, Engen, Wisloff, & Hoff, 2001). Alongside AE, muscle strength is a key physical quality and represents the foundation upon which muscular power can be developed (Stone, Sands, Pierce, & Newton, 2006). An increase in absolute muscle strength is often associated with improved relative strength and by extension, this can exert a positive effect on the power capabilities of an athlete (Wisloeff, Helgerud, & Hoff, 1998). Moreover, it has been demonstrated that high levels of muscle strength can increase sprint speed and CoD speed performances in elite male soccer players (Hartmann et al., 2015). With all the above in mind, the design and application of well-structured training interventions, which target key elements of physical performance (i.e., linear sprint-speed, CoD speed, strength, AE) in youth soccer players, is of utmost importance to reach success in competition (Stølen et al., 2005; Wisloeff et al., 1998).

Plyometric jump training (i.e., an eccentric muscle action immediately followed by a rapid concentric action during jumping tasks [PJT]) (Chaabene & Negra, 2017; Negra, Chaabene, Fernandez-Fernandez, et al., 2020; Negra et al., 2017) and power training using free weights (i.e., a slow eccentric muscle action immediately followed by a rapid concentric action without jumping [PT]) (Negra, Chaabene, Hammami, Hachana, & Granacher, 2016; Negra, Chaabene, Stöggl, et al., 2020) are safe and effective means to improve measures of physical fitness (e.g., linear sprint-speed, muscle strength/power, CoD speed, and repeated sprint ability [RSA]) in youth soccer players. Indeed, PJT seems to be a better training option in resource constrained environment since it can be carried out without additional equipment. For example, Negra et al. (2016) found that PJT, using body mass only, and resistance training using free weights represent effective training tools to improve maximal linear sprint-speed, CoD speed, and jumping ability, with different time courses of enhancement, in pre-peak height velocity (pre-PHV) male soccer players. More specifically, results showed large improvements in muscle strength following resistance training with no effects on this measure through PJT (Negra et al., 2016). Lesinski, Prieske, and Granacher (2016) conducted a meta-analysis on the effects and dose-response relationships of resistance training on measures of physical fitness in youth athletes. These researchers reported that free-weight resistance training induced larger effects on muscle strength and CoD speed than PJT.

Of note, there is limited empirical research that directly contrasts the effects of PT, using free weights, and PJT on measures of physical fitness in pre-PHV male soccer players. Previous studies have addressed the effects of resistance training only or PJT only and showed positive adaptations on AE. However, the effects of PJT and PT using free weights on AE is still unknown in pre-PHV male soccer players due to the lack of comparative studies. One recent study by Ramirez-Campillo et al. (2020) demonstrated moderate improvements (effect size [ES]=0.77) in a 20m multistage shuttle run test (MSRT) in male soccer players aged 17 years following a 7-week program of PJT. Additionally, Ferrete, Requena, Suarez-Arrones, and de Villarreal (2014) studied the effects of a long-term (i.e., 26 weeks) resistance training program in prepubertal male soccer players and observed large improvements (ES= 1.36) in the Yo-Yo intermittent recovery test following training, with no changes found in the control group. Overall, PJT and resistance training may have caused neuromuscular changes (i.e., muscle recruitment pattern) which contributed to a better running economy (Balsalobre-Fernández, Santos-Concejero, & Grivas, 2016; Denadai, de Aguiar, de Lima, Greco, & Caputo, 2017)

Based on the current body of literature, we aimed to contrast the effects of PJT and PT using free weights on measures of physical fitness (i.e., linear sprint-speed, CoD speed, AE, and muscle strength) in pre-PHV male soccer players. We hypothesized that PT using free weights would induce larger improvements on measures of physical fitness compared with PJT in pre-PHV male soccer players (Lesinski et al., 2016; Negra et al., 2016).

Methods

Participants

The sample size estimation was computed using G*Power software (version 3.1.6) (Faul, Erdfelder, Buchner, & Lang, 2009). With reference to a previous intervention study on the effects of 12 weeks of resistance training on maximal strength performance (i.e., 1RM half-squat) in pre-PHV male soccer players (Negra, Chaabene, Stöggl, et al., 2020), an *a priori* power analysis, with a type I error rate of 0.05 and 80% statistical power, was computed. The analysis indicated that overall, 21 participants would represent a sufficient sample with which to observe significant, large effects of time (Cohen d = 0.80) on maximal strength performance. Considering the potential for participant attrition, a total of thirty-three healthy, pre-PHV male soccer players, from the same regional soccer team, were recruited to take part in the study. Of note, all the groups followed the same soccer training program under the supervision of the same coaches. Participants were randomly assigned to a PT group (n = 11; age = 12.8±0.2 years; maturity-offset = -1.5±0.5 years; APHV = 14.3±0.3 years), a PJT group (n = 11; age = 12.7±0.3 years; maturity-offset = -1.7±0.6 years; APHV = 14.4±0.6 years), and an active control group (CG; n = 11; age = 12.8±0.3 years; maturity-offset = -1.6±0.6 years; APHV = 14.5±0.8). All players participated in a 11 vs. 11 soccer match lasting 90 min at the end of each training week (generally on Sundays). All participants were classified as experienced soccer players with 4.0 ± 1.2 years of systematic soccer training experience involving three-to-five training sessions per week. All players met the following inclusion criteria: (i) they had undertaken continuous soccer training over the past three months with no musculoskeletal injuries sustained, (ii) there was an absence of potential medical problems that could compromise participation or performance in the study, (iii) none had undergone any lower-extremity surgery in the two years before the study and (iv) none were engaged in any other sport or played with any other soccer club. The anthropometric characteristics of both groups are detailed in Table 1.

******Table 1 near here******

The active CG participated in a regular soccer-specific training program over the twelve-week intervention period with five training sessions per week lasting between 80 and 90 minutes each. The PT and PJT groups participated in three soccer-specific training sessions per-week, similar in content to those of the CG. The PT and PJT groups replaced two weekly soccer training sessions with PT and PJT sessions, respectively. The overall training time was identical between the three groups (Table 2). The soccer training included exercises to enhance fast footwork, technical skills and moves, and position and tactical games.

Table 2 near here

The maturity status of participants was determined according to the offset method. The maturity-offset was estimated using the predictive equation established by Mirwald, Baxter-Jones, Bailey, and Beunen (2002) as follows:

*Maturity-offset = -9.236 + (0.0002708·leg length and sitting height interaction) – (0.001663·age and leg length interaction) + (0.007216·age and sitting height interaction) + (0.02292·weight by height ratio*100).*

The study was conducted per the latest Declaration of Helsinki, and the protocol was approved by the local Ethics Committee of the ***blind for review purposes***. Signed informed consent was gained from the participants' parents or guardians following a verbal and a written explanation of the experimental protocol and its potential risks and benefits. The participants and their parents/legal guardians were told that they were free to withdraw from the study without penalty at any time and without explanation. All the players were examined by the team physician with a particular focus on orthopedic and other conditions that might preclude the execution of PT, PJT, or soccer training and competition. All players were found to be in good health.

Experimental design

A three-group randomized-controlled trial design was applied to examine the effects of PT vs. PJT on measures of physical fitness in pre-PHV male soccer players. For two sessions per week, the regular soccer training of the participants was replaced with PT using free weights or PJT. The control group continued to undertake its regular soccer training. The pre- and post-intervention assessments included tests of sprint-speed (i.e., 30-m sprint-speed with 5-, 10-, and 20-m split intervals), CoD speed (i.e., 10-m CoD test), muscle strength (i.e., half-squat one repetition maximum [1RM]), and AE (i.e., 20-m MSRT). All tests were conducted 48 hours after the players' most recent training session, at the same time of the day (7:30 a.m. to 9:30 a.m.), and under the same environmental conditions (29-33° C, no wind). Players who failed to execute 80% of the scheduled training sessions or who missed more than two successive sessions were excluded from the study. Fitness tests were performed in a fixed order over three days. On the first test day, anthropometric measurements were conducted, followed by the sprint-speed test and the CoD speed test. The second day was devoted to the MSRT. During the third day, players undertook the 1RM half-squat test. Two experienced strength and conditioning trainers, who were blinded to group allocation, conducted all measurements.

Aerobic endurance

AE was assessed using the MSRT, an incremental running test performed to maximal exertion. The MSRT is a highly recommended test to assess AE in pediatric populations (Tomkinson, Lang, Blanchard, Léger, & Tremblay, 2019) and was conducted as previously described (Leger, Mercier, Gadoury, & Lambert, 1988). The test consisted of shuttle runs between two lines which were spaced 20-m apart. The running pace began at 8.5 $km.h^{-1}$ and was increased 0.5 $km.h^{-1}$ each minute. The participants adjusted their running velocity according to auditory pacing signals provided by a calibrated beeper (SONY-ENG203®. Sony, Tokyo, Japan). The test is terminated when the participant can no longer sustain the required running pace and/or has failed to arrive within 2-m of the end line on two consecutive intervals. The last announced stage number was used as the AE index. To avoid undue fatigue, the test was performed only once. The MSRT presents high-to-very-high reliability in pediatric populations (intraclass correlation coefficient [ICC]=0.78 to 0.93) (Artero et al., 2011).

Change of direction speed

The 10-m CoD speed test was conducted as previously outlined (Meylan & Malatesta, 2009). The time needed to complete the test was used as a performance outcome and it was assessed using a single-beam infrared photocell device (Microgate SRL, Bolzano, Italy). Each participant performed two trials with a 3-min rest between each. The best trial was used for further analysis. The ICC for test-retest trials was 0.84 and the CV was 2.2%.

Linear sprint speed

Performance in the 30-m linear sprint-speed test was measured using an infrared photocell system (Microgate, Bolzano, Italy). Additionally, split sprint times at 5-m, 10-m, 20-m, and 30-m were analyzed. In total, five single-beam photoelectric gates were used. The between-trial recovery time was 2-min. The best performance out of two trials was used for further analysis. The ICCs for test-retest reliability were 0.94, 0.92, 0.92 and 0.89 for 5-m, 10-m, 20-m, and 30-m, respectively. The coefficients of variation (CVs) were 2.1, 1.7, 0.9, and 2.6% for 5-m, 10-m, 20-m, and 30-m, respectively.

Muscle strength

Before attempting the half-squat 1RM lift, the participants performed five-to-six repetitions with a relatively light load (~40% of their perceived 1RM), then three to four repetitions with a heavier load (~70% of their perceived 1RM), and, finally, a single repetition with 95% of their perceived 1RM. Participants then attempted a single repetition with the estimated 1RM load. If this weight was lifted with proper form, as judged by the qualified testers, the weight was increased by 1 to 2.5 kg, and the participant attempted another repetition. Failure was defined as a lift falling short of the full range of motion on at least two attempts spaced at least two minutes apart. The 1RM was typically determined within four to five trials.

Power training using free weights and plyometric jump training programs

The two training programs were conducted during the end portion of the in-season period. Before every PT and PJT session, a standardized 8-12 min warm-up was completed and this included self-selected low intensity running, coordination exercises, dynamic movements (i.e., lunges, skips), incremental-intensity sprints, and dynamic stretching for the lower limb muscles. The PT and the PJT sessions lasted between 35 and 40 minutes. At the beginning of each training week, the first PT and PJT sessions were performed at least 48 hours after the soccer match that was scheduled on the previous weekend. More specifically, soccer matches were mostly organized on Saturday mornings. Therefore, training sessions started on Monday mornings. The second session was completed 72 h after the first session (mostly Thursday mornings) to provide a sufficient recovery period between sessions.

The PT program consisted of half-squat exercises executed using free weights with 4 sets of 8- to 12-repetitions each and two minutes of inter-set rest. The training load was adjusted every four weeks and was increased throughout the training period. During the first week, subjects exercised at 40% of their 1RM. During the second week, the load was increased to 50% of 1RM and during the third week to 60% of 1RM. During the fourth week of training, the load was decreased to 40% 1RM to avoid overtraining and to facilitate adaptation. This 3:1 cycle was applied three times over the twelve-week training period. In performing the exercises, the participants were instructed to bend the knees slowly (i.e., to execute slow eccentric phase) and to perform the concentric phase as fast as possible with a break of approximately two seconds between each repetition (David G Behm, 1995).

For the PJT, all sessions were completed on an artificial turf pitch to minimize the landing impact and to be as soccer-specific as possible. In brief, every first PJT session in each week focused on improving the vertical leap (i.e. CMJs), whereas every second PJT session focused on improving horizontal-jump ability (i.e. bilateral horizontal ankle hops). The players were instructed to perform all PJT exercises at maximal intensity (i.e., maximal height and horizontal distance with minimal ground contact time, for vertical and horizontal jumping, respectively). Proper technique was ensured through verbal cues and demonstration by the researchers throughout the intervention. To limit stress on musculotendinous unit, training volume was progressively increased. The total number of ground contacts per week started at 112 during the first week and were increased to 280 after 12 weeks. In addition, sets and repetitions were equally divided between vertical and horizontal jumps. Approximately 90 seconds of rest was allowed between each set. Besides the above-described programs, both experimental groups performed controlled-velocity abdominal curl and back extension exercises in every session, executing 6 sets of 15 repetitions. These core exercises were included to provide a general conditioning effect as suggested in the position stand of D. G. Behm, Faigenbaum, Falk, and Klentrou (2008).

Statistical Analyses

Data are presented as group mean values and standard deviations. After data normality was verified with the Shapiro-Wilk test, a one-way analysis of variance (ANOVA) was used to detect baseline between-group differences. A two-way ANOVA with repeated measures on time was used to group-specifically analyze all dependent variables (groups: control, PJT, HiVRT; times: pre, post). Post-hoc tests with Bonferroni adjustment were conducted to identify statistically significant comparisons. Effect sizes for the main effects of 'group' and 'time', as well as group × time interactions, were taken from the ANOVA output (partial eta squared transferred to Cohen's *d*). Within-group Cohen's *d* effect sizes (ES) were computed. ES can be classified as small ($0.00 < d < 0.50$), moderate ($0.50 \leq d < 0.80$), and large ($d \geq 0.80$) (Cohen, 1988). Within-session reliability was assessed using ICC and CV (Cohen, 1988). Statistical analyses were carried out using the STATISTICA statistical package (Version 8.0; StatSoft, Inc., Tulsa, USA). Significance levels were set at $\alpha = 5\%$.

RESULTS

All participants received the treatments as allocated. The overall rate of compliance to training interventions was 95%.

No significant between-group baseline differences were observed for any descriptive variable (Table 1) or physical fitness (Table 3) measure. The main effects of group, time, and group × time interactions are displayed in Table 3.

Table 3 near here

The analyses revealed significant group × time interaction effects for 5-m, 10-m, 20-m, 30-m, 10-m CoD speed, MSRT, and half-squat 1RM (all $p<0.05$; d=1.00 to 3.12) (Table 3). Post-hoc analyses revealed that the PT using free weights generated moderate-to-large improvement in all sprint-speed intervals (ES=0.71 to 1.23; Δ4.5% to 7.6%, all $p<0.05$), 10-m CoD speed (ES=1.38; Δ7.2%; $p<0.001$), MSRT (ES=0.95; Δ13.8%; $p<0.01$), and half-squat 1RM (ES=1.35; Δ30.6%; $p<0.001$). For PJT, the post-hoc analyses demonstrated moderate increases in 10-m, 20-m, 30-m sprint (ES=0.51 to 0.73; Δ3.5% to 4.7%; $p<0.05$), 10-m CoD speed (ES = 0.96; Δ6.5%; $p<0.001$), and MSRT (ES = 0.71; Δ14.1%; $p<0.01$). However, no significant changes were noted for the 5-m sprint (ES = 0.71; Δ6.0%; $p>0.05$) and half-squat 1RM (ES = 0.16; Δ4.2%; $p>0.05$) for the PJT group. No significant changes were observed for the CG in any of the measured variables (ES = -0.05 to 0.20; Δ-0.2 to 2.4%; all $p>0.05$).

Discussion

This study compared the effects of a 12-week PT program, using free weights, and a PJT program on measures of physical fitness in pre-PHV male soccer players. Our findings show that PT and PJT are effective tools to enhance pre-PHV male soccer players' physical fitness. Specifically, PT, with free weights, has an advantage over PJT if the goal is to additionally improve acceleration and muscle strength.

Aerobic endurance

A high level of AE allows soccer players to effectively cope with the physical demands of a soccer match (Stølen et al., 2005). Our results revealed significant, large and moderate improvements in AE after the PT (d=0.95) and PJT (d=0.71) programs, respectively. For the CG, no significant change in AE was observed. These findings are in agreement with earlier studies. For example, Ramirez-Campillo et al. (2020) investigated the effects of a 7-week PJT program on AE in male soccer players aged 17 years and observed moderate increases (i.e., MSRT) (ES=0.77). In another study, Ramirez-Campillo et al. (2015) revealed a moderate improvement in AE (i.e., MSRT) (Δ10%; ES= 0.49) after six weeks of PJT in male soccer players aged 14 years. In a systematic review with meta-analysis, van de Hoef, Brauers, van Smeden, Backx, and Brink (2019) reported significant improvement in AE following PJT in male soccer players. Ferrete et al. (2014) examined the effects of a 26-week program of strength (i.e., ¼ squat) and high-intensity exercises (i.e., deep jumps, CMJ with weight, and sprint-speed exercises) on AE (i.e., YoYo intermittent recovery test) in prepubertal male soccer players. These researchers reported a large enhancement of AE following training (Δ49.57%, ES = 1.39). It is worth noting that the observed improvements in AE following PT and PJT might have occurred independently of direct measures of AE such as maximal oxygen uptake or lactate threshold (Denadai et al., 2017). More specifically, PT and PJT may have caused neuromuscular changes (i.e., muscle recruitment pattern) which contributed to better running economy (Balsalobre-Fernández et al., 2016; Denadai et al., 2017). Markovic and Mikulic (2010) previously argued that improvement in measures relating to neuromechanical factors (e.g., increased force-generating capacity) and tendon stiffness could lead to increased AE performance. Although not measured in this study, previous research has also demonstrated better force-generating capacity and improved tendon stiffness following resistance training (Kubo, Ikebukuro, Yata, Tsunoda, & Kanehisa, 2010a, 2010b). Increased tendon stiffness facilitates a faster transfer of force from contracting muscles to moving bones (Legerlotz, Marzilger, Bohm, & Arampatzis, 2016), reduces the amount of energy expended (i.e. better economy) (Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999), and improves athletes' ability to change direction during MSRT (Michailidis, Tabouris, & Metaxas, 2019). Overall, PT using free weights and PJT are both effective means with which to improve AE in pre-PHV male soccer players.

Muscle strength

The results of this study indicated large increases in muscle strength (ES=1.35) following PT. However, no significant changes in muscle strength were detected after PJT and regular soccer training (i.e., CG). This corresponds with the principle of training specificity which dictates that training-related adaptations are larger when the training features (e.g., type of exercise, contraction mode, movement velocity) are aligned with the tested activity (David G Behm, 1995). Negra, Chaabene, Stöggl, et al. (2020) examined the effects of a 12-week RT program and a PJT program on measures of muscle strength (i.e., 1RM half squat) in pre-PHV male soccer players. The authors revealed significant, large improvements in 1RM half-squat after RT (Δ27.9% d= 3.1) with no significant effect observed due to PJT. In a meta-analytical study, van de Hoef et al. (2019) demonstrated no effects of PJT on muscle strength in male soccer players. Of note, the participants in this study were instructed to execute the descent phase of the squat exercise in a slow fashion, emphasizing the eccentric muscle action during performance. Such a practice may have stimulated greater muscle strength adaptations during eccentric actions, thus contributing to a higher overall level of strength. Indeed, there is compelling evidence indicating that eccentric exercises result in greater strength adaptations compared with concentric or isometric exercises (Roig et al., 2009). In contrast, the stimulus delivered to the muscle by the PJT did not seem to be effective to drive strength development. PJT facilitates high-velocity movement during the eccentric phase of a given jumping movement. This has been shown to be less effective in generating strength adaptive responses compared with slow velocity eccentric phases during RT, probably due to the lower time under tension associated with quicker movements (Burd et al., 2012). Considering the maturity level of the participants in this study, the observed muscle strength gains after PT were likely caused by neural factors (e.g., motor unit recruitment/synchronization, rate coding) (Legerlotz et al., 2016) as opposed to hypertrophic gains (Moran et al., 2017). Based on the findings of the present study, as well as earlier investigations, it should be advised to favor PT over PJT if the goal is to improve muscle strength in pre-PHV male soccer players.

Change of direction speed

The results of this study revealed significant, large CoD speed performance improvements after PT (d=1.38) and PJT (d=0.96) with no significant changes observed in the CG. These findings corroborate with existing literature (Chaabene et al., 2020; Negra, Chaabene, Stöggl, et al., 2020). For instance, Meylan and Malatesta (2009) studied the effects of eight weeks of PJT on CoD speed (i.e., T-test) in male soccer players aged 13 years. These authors reported significant, large improvements in CoD speed performance following training (Δ9.6%, ES=2.8). Similarly, Negra et al. (2017) reported large improvements in CoD speed performance (i.e., T-test) (Δ7%) after eight weeks of PJT in prepuberal male soccer players. Christou et al. (2006) reported large improvements in CoD speed (i.e., 10×5-m shuttle run) after eight (ES = 0.83) and 16 weeks (ES = 1.74) of resistance training in young male soccer players aged 14 years. Furthermore, a recently published systematic review with meta-analysis demonstrated significant, large effects (ES=-0.82) of resistance training on CoD speed performance in youth and young physically active and athletic adults (Chaabene et al., 2020). There is evidence that eccentric strength contributes to CoD speed performance, particularly during the deceleration phase as the athlete attempts to alter their course or stop (Chaabene, Prieske, Negra, & Granacher, 2018). In this context, it seems plausible to suggest that PT using free weights (i.e., low eccentric immediately followed by a rapid concentric muscle action) and PJT (i.e., eccentric immediately followed by concentric muscle action during jumping) might have improved the eccentric strength of the lower limbs. The observed training-related improvements in CoD speed appear to be mainly caused by neural factors such as higher level of motor unit recruitment/synchronization and increased rate coding (Komi, 2003).

Linear sprint speed

PT induced moderate-to-large (ES = 0.71 to 1.23) sprint speed improvements, while PJT induced small-to-moderate enhancements (ES = 0.51 to 0.73). No significant changes were observed for the CG ($p>0.05$). Sprint speed has previously been observed to improve after PJT and RT in pre-PHV male soccer players (Negra et al., 2016; Negra, Chaabene, Stöggl, et al., 2020). Improvements in sprint-speed performance after PJT and PT appear to be mainly related to increases in neuromuscular activation of the trained muscles (Hammami, Gaamouri, Shephard, & Chelly, 2019). More specifically, increases in the number or firing frequencies of active motor units or changes in the recruitment pattern of the motor units, primarily those of fast-twitch muscle fibers, might account for the observed results (Hakkinen, 1985). These factors may increase rate of force development (Rodríguez-Rosell, Pareja-Blanco, Aagaard, & González-Badillo, 2018), maximal force production (Taber, Bellon, Abbott, & Bingham, 2016) and the efficiency of the stretch-shortening cycle (Taube, Leukel, & Gollhofer, 2012) which would, in turn, benefit sprint-speed performance, probably through changes in stride length and stride frequency (Haugen, Seiler, Sandbakk, & Tønnessen, 2019). Unlike PT, no significant improvement in the 5-m distance was observed after PJT. There is evidence that generating high mean horizontal forces is the main performance-determining factor in quickly accelerating from a standing position (Haugen, McGhie, & Ettema, 2019; Nagahara, Mizutani, Matsuo, Kanehisa, & Fukunaga, 2018). In this context, it can be hypothesized that increased muscle strength following PT contributed to better horizontal force production during the acceleration phase of sprinting. However, the horizontal stimulus during PJT appeared not to be enough to trigger positive adaptive responses (i.e., greater horizontal force) during acceleration in this case. In sum, PT seems to be more effective than PJT in improving sprint speed in pre-PHV male soccer players.

We acknowledge the absence of biomechanical and electrophysiological testing methods in this study. Therefore, to gain insights related to the physiological adaptive mechanisms of PT vs. PJT, future studies should seek to assess physiological parameters such as using electromyography in pre-PHV male soccer players. Additionally, because the muscle strength test (i.e., half-squat 1RM) closely matches the exercise used during PT, the observed higher muscle strength-related adaptations following PT compared with PJT should be interpreted with caution.

Conclusions

The main findings of this study showed that PT and PJT were effective in improving various measures of physical fitness in pre-PHV male soccer players. Particularly, to additionally enhance acceleration and muscle strength, PT using free weights should be favored over PJT.

Acknowledgments

The authors would like to thank the participants for volunteering their time and effort for the study.

Data availability statement

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

Disclosure statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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