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Effects of plyometric training on components of physical fitness in prepuberal male soccer athletes: The role of surface instability

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***Running head**: plyometric training in youth*

ABSTRACT

Previous studies contrasted the effects of plyometric training (PT) conducted on stable vs. unstable surfaces on components of physical fitness in child and adolescent soccer players. Depending on the training modality (stable vs. unstable), specific performance improvements were found for jump (stable PT) and balance performances (unstable PT). In an attempt to combine the effects of both training modalities, this study examined the effects of PT on stable surfaces compared to combined PT on stable and unstable surfaces on components of physical fitness in prepuberal male soccer athletes. Thirty-three boys were randomly assigned to either a PT on stable surfaces (PTS; n=17; age = 12.1 ± 0.5 years; height = 151.6 ± 5.7 cm; body-mass = 39.2 ± 6.5 kg; maturity offset = -2.3 ± 0.5 years) or a combined PT on stable and unstable surfaces (PTC; n=16; age = 12.2 ± 0.6 years; height = 154.6 ± 8.1 cm; body-mass = 38.7 ± 5.0 kg; maturity offset = -2.2 ± 0.6 years). Both intervention groups conducted four soccer-specific training sessions per-week combined with either two PTS or PTC sessions. Pre and post eight weeks of training, proxies of muscle power (e.g., countermovement jump [CMJ], standing-long-jump [SLJ]), muscle strength (e.g., reactive-strength index [RSI]), speed (e.g., 20-m sprint test), agility (e.g., modified Illinois change of direction test [MICODT]), static balance (e.g., stable stork-balance-test [SSBT]), and dynamic balance (unstable stork-balance-test [USBT]) were tested. An ANCOVA model was used to test between-group differences (PTS vs. PTC) at post-test using baseline outcomes as covariates. No significant between-group differences at post-test were observed for CMJ (p>0.05, d=0.41), SLJ (p>0.05; d=0.36), RSI (p>0.05, d=0.57), 20-m sprint test (p>0.05, d=0.06), MICODT (p>0.05, d=0.23), and SSBT (p>0.05; d=0.20). However, statistically significant between-group differences at post-test were noted for the USBT (p<0.01, d=1.49) in favor of the PTC group. For most physical fitness tests (except RSI), significant pre-post improvements were observed for both groups (p<0.01, d = 0.55-3.96). Eight weeks of PTS or PTC resulted in similar performance improvements in components of physical fitness except for dynamic balance. From a performance enhancing perspective, PTC is recommended for pediatric strength and conditioning coaches since it produced comparable training effects as PTS on proxies of muscle power, muscle strength, speed, agility, static balance and additional effects on dynamic balance.

Key words: Youth, football, stretch-shortening cycle, athletic performance, balance.

INTRODUCTION

It has previously been shown that muscle power (e.g., jumping), speed (e.g., linear sprint), and agility represent major determinants of soccer performance (23, 27, 39). Numerous studies indicated that plyometric training (PT) is an effective means to improve components of physical fitness, particularly in youth soccer (30).

Plyometric training refers to exercises involving jumping, hopping, and skipping that are characterized by eccentric contractions of the muscle-tendon unit immediately followed by concentric contractions which is also referred to as the stretch-shortening-cycle (23). The beneficial effects of PT on components of physical fitness (i.e., speed, power, strength, and agility) have been well-documented in the literature in the form of original work (6, 26, 32, 33), systematic reviews and meta-analyses (1, 2, 3, 20) for untrained and trained youth as well as adults.

More recently, the inclusion of exercises using unstable surfaces/training equipment in PT received interest in the literature (5, 13, 17, 31). In this context, Behm and Colado, (5) demonstrated that strength training under unstable conditions resulted in significant performance improvements in measures of muscular power, probably due to higher muscle activations when performing exercises on unstable surfaces. Particularly in soccer, athletes are often confronted with highly unstable soccer-specific tasks (e.g., jumping, change-of-direction) due to factors like opponents, grass, uneven natural turf etc (13).

According to the principle of training specificity, training should mimic a competition-specific demand which is why it appears plausible to argue that PT should be conducted on unstable surfaces (13, 28). Previous studies contrasted the effects of PT on stable versus unstable surfaces on components of physical fitness in child (28) or adolescent soccer athletes (13). Negra et al. (28) studied the effects of eight weeks of PT on stable vs. unstable surfaces on measures of physical fitness in prepuberal male soccer players. The authors reported comparable performance improvements on proxies of muscle power (e.g., countermovement jump-height [CMJ], standing-long-jump), speed (e.g., 10-, 20-, 30-m sprint test), dynamic balance (e.g., Y-balance test), and agility (e.g., Illinois change of direction test) following both training modalities (28). An additional training effect in favor of the unstable training group was solely found for static balance (e.g., stork balance test) (28). Further, Granacher et al. (13) examined the impact of PT on stable vs. unstable surfaces in sub-elite adolescent soccer players. Findings of this study (13) demonstrated similar performance improvements in both groups for measures of muscular power (e.g., drop-jumps), speed (e.g., 10-m sprint test), agility (e.g., figure-8 run test), and balance (e.g., center of pressure displacement during one-legged stance). However, PT on stable surfaces produced larger effects on vertical jump performance (i.e., CMJ-height) compared to the unstable group.

Taken the findings of these two studies together (13, 28), PT on stable surfaces resulted in larger improvements in jump performance (13), while PT on unstable surfaces produced larger improvements in balance performance (28). Moreover, the effects of combined PT on stable and unstable surfaces have not yet been examined in youth athletes. Thus, it is timely and imperative to study the effects of combined PT (stable and unstable) to enhance the likelihood of improving both, jump and balance performance at the same time and with one training intervention.

Therefore, in an attempt to fill this void in the literature, this study aimed at examining the effects of short-term (i.e., 8 weeks) in-season PT conducted either on stable (PTS) or stable and unstable surfaces (PTC) on components of physical fitness (i.e., muscle power, strength, speed, agility, static and dynamic balance) in prepuberal male soccer athletes. With reference to the relevant literature (28, 37), we hypothesized that the PTC group achieves higher training-induced performance improvements on measures of physical fitness, particularly in balance and agility compared with the PTS group.

METHODS

Experimental approach to the problem

When conducting research in sub-elite and elite sports, researchers are often confronted with limitations in terms of sample size that are not present when doing research with the general population. For this reason, a two-group repeated measures experimental design was applied in this study to examine the effects of PTS vs. PTC on components of physical fitness in prepuberal male soccer athletes. Of note, the PTS group served as active comparator. We decided not to include an additional unstable intervention arm due to sample size limitations and because we already contrasted the effects of stable versus unstable PT on measures of physical fitness in youth soccer athletes in previous studies (13, 28).

The two PT programs (PTS and PTC) were conducted during the in-season period of the soccer season. Two weeks before baseline testing, two sessions were performed to get subjects familiarized with the applied physical fitness tests. Pre- and post-training, tests for the assessment of proxies of muscle power (i.e., countermovement jump [CMJ], standing-long-jump [SLJ]), strength (i.e., reactive-strength index [RSI]), speed (i.e., 20-m sprint test), agility (i.e., modified Illinois change of direction test [MICODT]), static balance (i.e., stable stork-balance-test [SSBT]), and dynamic balance (i.e., unstable stork-balance-test [USBT]) were conducted. All tests were scheduled at least 48 hours after the last training session or competition.

Subjects

Thirty-seven healthy young athletes from a regional soccer team were randomly assigned either to a PTS group (n=21) or a PTC group (n=16). All participants were classified as experienced soccer players with 4.0 ± 1.2 years of systematic soccer training involving 3 to 5 training sessions per week. Anthropometric data of both groups are presented in Table 1. Athletes who missed more than 20% of the total training sessions and/or more than two consecutive sessions were excluded from the study (27). Maturation status of the participants was determined at the beginning and after eight weeks of training according to the predicted age at peak-height-velocity (APHV) (19). All procedures were approved by the Institutional Review Committee for the ethical use of human subjects at Ksar Saïd University. Written informed parental consent and participant assent was obtained prior to the start of the study. All youth athletes and their parents/legal representatives were informed about the experimental protocol and its potential risks and benefits before the commencement of the research project. Participants were allowed to withdraw from the study at any time and without giving any reason.

--Table 1 near here--

Soccer training

Over the eight-week intervention period, training included four sessions per week each lasting between 80-90 min. Both intervention groups conducted four soccer-specific training sessions per week in addition to either two PTS or two PTC sessions. Thus, the overall exposure time to training was identical between the two experimental groups. Soccer training included training of fast footwork, technical skills and moves (easy/difficult), position games (small/big), and tactical games with various objectives (27).

Plyometric training

The two experimental groups (i.e., PTS and PTC) participated in an eight-week in-season PT program with two PT sessions per week. The two PT sessions were integrated into the regular training routine of the soccer team. The second PT session was completed 72 h after the first one so as to provide a sufficient recovery period between sessions. Each session lasted between 80-90 min. The PT drills lasted between 25 to 30 minutes. The PT protocol was based on previously published recommendations for training intensity and volume from Bedoya et al. (3). During every PT session, two-footed ankle hops forward exercises and CMJs were performed. To limit stress on the musculotendinous unit, training volume and intensity were progressively increased (Table 2). While participants of the PTS group performed all jump exercises on stable surfaces, subjects in the PTC group executed the same exercises alternated on stable and highly unstable surfaces that are frequently used during athletic training and rehabilitation (i.e., Airex® Balance Pad and Thera-Band© Stability Trainer). Both sessions consisted of a volume of 8-12 sets with 6-10 repetitions. The total number of ground contacts per week was 50 during the first week and gradually increased to 120 after eight weeks of training. A 90-s rest was provided between each set of exercise.

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General testing procedures

The warm-up program for all tests was conducted on stable surface for both groups and it included 5 min. of sub-maximal running with change of direction exercises, 10 min. of submaximal plyometrics (two jump exercises of 20 vertical [i.e., CMJ] and 10 horizontal jumps [i.e., two-footed ankles hop forward]), dynamic stretching exercises, and 5 min. of a sprint-specific warm-up (27). All tests were separated by a 5-10 min. break in-between. Each player participated in a familiarization trial and two test trials. Another rest period of 3 min. was provided between trials. The best out of the two test trials was used for further statistical analyses.

Muscle power

Countermovement jump test

During the CMJ, participants started from an upright erect standing position, performed a fast downward movement by flexing the knees and hips which were immediately followed by a rapid leg extension resulting in a maximal vertical jump. Throughout the execution of the test, participants maintained their arms akimbo. CMJ techniques were visually controlled by the first author of this study. Jump height was recorded using an Optojump photoelectric system (Microgate, SRL, Bolzano, Italy). The intraclass correlation coefficient (ICC) for test-retest reliability was 0.95.

Standing-long-jump-test

The starting position of the SLJ required subjects to stand with their feet shoulder-width apart behind a starting line and their arms loosely hanging down. On the command ready, set, go, participants executed a countermovement with their legs and arms and jumped at maximal effort in the horizontal direction. Participants had to land with both feet at the same time and were not allowed to fall forward or backward. The horizontal distance between the starting line and the heel of the rear foot was recorded via tape measure to the nearest 1-cm. The ICC for test-retest reliability was 0.98.

Muscle strength

Reactive strength index

During RSI, participants executed five repeated bilateral maximal vertical hops using an Optojump photoelectric system (Microgate, SRL, Bolzano, Italy) for performance assessment. Prior to testing, youth athletes were instructed to maximize jump height and minimize ground contact time. The first jump was excluded and the 4 remaining trials were averaged for the calculation of RSI using the following formula:

RSI= jump height (mm) / ground contact time (ms).

Speed

Twenty-meter linear sprint performance was assessed using an electronic timing system (Microgate, Bolzano, Italy). Participants started in a standing start position 0.3-m before the first infrared photoelectric gate, which was placed 0.75-m above the ground to ensure it captured trunk movement and avoided false signals via limb motion. In total, four single beam photoelectric gates were used. The ICC for test-retest reliability was 0.91.

Agility

The modified Illinois change of direction test

Performance in the MICODT was assessed using an electronic timing system (Microgate SRL, Bolzano, Italy). The applied procedures were in accordance with a previously published study (14). The MICODT involves placing 4 markers to indicate an area that is 5 m long and 5 m wide. In the center of the area, 3 markers were placed 2.5 m apart (Figure 1). Participants started in a prone position with the chin touching the surface of the starting line. Athletes accelerated for 5 m, turned around and returned back to the starting line, and swerved in and out of 3 markers, completing 5-m sprints to finish the MICODT speed course. Participants were instructed not to cut over the markers but to run around them. If a participant failed to follow these instructions, the trial was terminated and re-started after a 3 min recovery period. The ICC for test-retest trials was 0.92.

--Figure 1 near here--

Static and dynamic balance

Stork-balance-test on stable (static balance) and unstable surface (dynamic balance)

The stork-balance-test was used to test static and dynamic balance on the dominant leg (22). The leg athletes preferably kicked a soccer ball with was considered the dominant leg (15). During the test, subjects stood on the dominant leg while the non-dominant leg was flexed in the knee with the foot resting on the knee cap of the dominant leg. On the "go" signal, subjects stood in the stork balance test position, raised the heel of their foot from the floor and held hands on hip. Participants were asked to maintain this position for as long as possible. The test was terminated when the heel of the dominant leg touched the ground or the foot moved away from the knee cap. This test was carried out under static conditions (stable stork-balance-test [SSBT]) and dynamic conditions (unstable stork-balance-test [USBT]) using an Airex balance pad. The stork-balance-test was timed using a stop-watch. The ICC for test-retest trials was 0.89, 0.83 for the SSBT and the USBT, respectively.

Statistical Analyses

Data were tested for normal distribution using the Shapiro-Wilk's test. Between-group differences at baseline were tested using independent t-tests. Furthermore, training effects were evaluated using an ANCOVA statistical model with baseline measurements entered as covariates. Additionally, effect sizes (ES) were determined by converting partial eta-squared from the ANCOVA output to Cohen's d. To evaluate within-group pre-to-post performance changes, paired sample t-tests were applied (29). ES were determined from means, standard deviations, and correlation coefficients using the statistical software package G*Power (version 3.1.6). According to Cohen (8), ES can be classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$). Test-retest reliability was assessed using the intraclass correlation coefficient (ICC) $_{(3,\ 1)}$ (41). By referencing to Coppieters et al. (9), an ICC below 0.40 as poor, between 0.40 and <0.70 as fair, between 0.70 and <0.90 as good, and ≥0.90 as excellent. Data are presented as group mean values and standard deviation for the pre-test and adjusted means and standard deviation for the post-test. The level of significance was established at $p \leq 0.05$. SPSS 20.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

RESULTS

All subjects received treatment conditions as allocated. Four subjects in the PTS group dropped out because they left the youth soccer training center for personal reasons. Thus, 33 athletes completed the training program with an adherence rate of 93%. None reported any training or test related injuries. Table 3 displays test data for all components of physical fitness measured at pre- and post-intervention. There were no statistically significant baseline differences between-group in chronological age, body height, body mass, APHV, and soccer experience, suggesting that: i) the maturation level of the boys was prepuberal, and ii) both groups had similar age and anthropometric characteristics (Table 1).

Muscle power

Countermovement jump test

Our ANCOVA analysis indicated no significant between-group differences at post-test for the CMJ (p>0.05, d=0.41) (Table 3). Significant pre-to-post changes were found for both groups, the PTS (Δ8.4%, d=1.95, p<0.01) and the PTC (Δ7.1%, d=0.59, p<0.05).

Standing-long-jump-test

The ANCOVA model revealed no significant between-group differences at post-test for the SLJ (p>0.05; d=0.36) (Table 3). In addition, significant pre-to-post changes were detected in the PTS group (Δ25.3%, d=3.96, p<0.001) and the PTC group (Δ5.4%, d=0.99, p<0.01).

Muscle strength

In terms of the RSI test, no significant between-group differences were found at post-test (p>0.05, d=0.57) (Table 3). In addition, no significant pre-to-post changes were detected in the PTS group (Δ6%, *d*=0.25, $p>0.05$). However, a significant performance decline was found in the PTC group (Δ14%, *d*=1.94, $p<0.01$).

Speed

No significant between-group differences were observed at post-test ($p>0.05$, $d=0.06$) (Table 3). Significant pre-to-post changes were found for the PTS group (Δ2.9%, $d=0.78$, $p<0.05$) and the PTC group (Δ1.6%, $d=0.58$, $p<0.05$).

Agility

ANCOVA results indicated no significant between-group differences at post-test for the MICODT ($p>0.05$, $d=0.23$) (Table 3). Pre-to-post training values increased significantly in both groups, the PTS and the PTC group (both Δ2%, $d=0.62$, 1.15, $p<0.01$, 0.001, respectively).

Static and dynamic balance

With regards to static balance (i.e., SSBT), no significant between-group differences were found after training ($p>0.05$; $d=0.20$) (Table 3). Significant pre-to-post changes were detected in the PTS group (Δ32%, $d=0.55$, $p<0.05$) and in the PTC group (Δ34%, $d=1.57$, $p<0.01$). For dynamic balance (i.e., USBT), our statistical analysis indicated a significant between-group difference at post-test ($p<0.01$, $d=1.49$) in favor of the PTC group (Table 3). In addition, PTC resulted in significant pre-to-post changes in the USBT (Δ84%, $d=2.59$, $p<0.001$). Likewise, PTS produced a significant enhancement in the USBT (Δ53%, $d=1.28$, $p<0.001$) (Figure 1).

-Table 3 near here-

-Figure 2 near here-

DISCUSSION

To the authors' knowledge, this is the first study to examine the effects of PTS compared with PTC on components of physical fitness in prepuberal male soccer athletes. We hypothesized that PTC compared with PTS produces larger performance improvements in balance and agility. The main findings of this study were that (i) no significant between-group differences were found at post tests for measures of muscle power, strength, speed, agility, and static balance and (ii) PTC induced larger performance improvements in dynamic balance (i.e., USBT) compared with PTS.

In this study, both PT protocols induced similar performance improvements in measures of vertical (i.e., CMJ) and horizontal (i.e., SLJ) jump performance in prepuberal male soccer athletes. This is in line with the literature. In fact, Meylan and Malatesa (23) were able to show that eight weeks of PTS with two training sessions per week resulted in significant improvements in CMJ height (Δ7.9%, p<0.01) in early-puberal male soccer players aged 13 years. Likewise, Michailidis et al. (24) revealed that PTS conducted twice a week produced significant improvements in CMJ height after six (Δ18.5%, p<0.05) and twelve weeks (Δ27.6%, p<0.05) of training in prepuberal male soccer players with a mean age of 10.9 ± 0.7 years. In addition, Michalidis et al. (24) showed significant increases in SLJ performance after six (Δ2.6%, p<0.05) and twelve weeks (Δ4.2%, p<0.05) of training. Further, Negra et al. (27) demonstrated significant improvements in CMJ height performance after eight weeks of PT conducted on stable (Δ13%, p<0.01) and unstable surfaces (Δ7%, p<0.05) in prepuberal male soccer players (U13). The same authors reported comparable improvements in SLJ performance when PT was conducted on stable (Δ6%, p<0.01) and unstable surfaces (Δ6%, p<0.01) (28).

In another study, Granacher et al. (13) revealed larger performance improvements in CMJ height (Δ12.9%, p<0.01) after eight weeks of PT conducted on stable compared to unstable surfaces in sub-elite adolescent male soccer athletes with a mean age of 15.2 ± 0.5 years. The present findings extended the previous studies reported in the literature by showing that prepuberal male soccer athletes are able to significantly increase their horizontal and vertical jump performance following both PTS and PTC (Table 3). Given that prepuberal athletes' hormonal situation (lack of circulating anabolic hormones) does most likely not allow muscle hypertrophy, we speculated that the observed marked improvements in jump performance were caused by neural factors in terms of increased motor unit recruitment (i.e., intra-muscular coordination) and better synergistic and less antagonistic muscle activation strategies (i.e., inter-muscular coordination) (20).

In terms of muscle strength, our study revealed no significant between-group differences in RSI at post-test. The RSI is an indicator of athletes' ability to quickly change from eccentric to concentric muscle action (10). Even though we could not detect any significant between-group differences at post-test, we were still able to identify significant within-group pre-to-post improvements (Δ6%) in RSI for PTS. In accordance with our data, Meylan and Malatesta, (23) reported increases, albeit non-significant, in RSI (Δ17.6%) following eight weeks of PTS in 13-years-old boys. Likewise, Lloyd et al. (18) showed significant training effects after four weeks of PTS in the RSI in 12-year-old boys (Δ~10%, $p<0.05$). Previous studies suggested that foremost greater stretch-reflex contributions (40), rate-of-force development (21) and increased motor unit recruitment (35) are responsible for RSI improvement. Of note, in the PTC group, we were able to show significant pre-to-post performance declines in RSI. This finding is mainly due to longer ground contact times when performing plyometrics on unstable surfaces because the RSI represents the ratio between jump height and ground contact time (18, 31). Therefore, it is suggested that coaches conduct PTS if the goal is to enhance RSI.

In terms of the 20-m sprint test, our findings illustrated that eight weeks of either PTS or PTC resulted in no significant between-group differences at post-test in prepuberal male soccer athletes (Table 3). The observed reductions in sprint times (2.9% for PTS and 1.6% for PTC) are in line with findings from previous studies. For instance, Chaabene and Negra (6) reported that two PTS sessions per week induced a 3% improvement in the 20-m sprint test in prepuberal male soccer players (U13). Similarly, Franco-Marquez et al. (11) were able to show for young soccer players with a mean age of 14.7±0.5 years that the addition of six weeks of resistance training and PTS to standard soccer training produced greater gains (Δ1.1%, $p<0.05$) in 20-m sprint test performance than soccer training alone. Likewise, Rodriguez-Rosell et al. (36) extended the findings of the aforementioned studies, in that they additionally observed training-related improvement in speed performance (10-m [Δ-2.7%, p<0.01]; 10-20-m [Δ-3.5%, p<0.001]; and 20-m [Δ-2.7%, p<0.001]) following six weeks of combined PTS and resistance training in prepuberal male soccer players. Further, Söhnlein et al. (38) reported a clear reduction in 20-m sprint test performance (Δ3.2%) following sixteen weeks of PTS program in pre- to mid-puberal male soccer players with a mean age of 13±0.9 years. In the same context, Negra et al. (26) observed a significant enhancement in 20-m sprint test performance (Δ4%, $p<0.05$) after twelve weeks of PTS in prepuberal male soccer players with a mean age of 12.7 ± 0.3 years. Granacher et al. (13) reported a significant 10-m performance enhancement in the unstable and PTS groups (Δ1.5%, 1.9%, respectively; both p<0.05) and a tendency toward significant 30-m performance improvement (Δ0.7%, 0.9%, respectively; p=0.08) after eight weeks of training. In line with the previous study, Negra et al. (28) observed a significant improvement for all sprint intervals after eight weeks of unstable (0-10-m [Δ6%], and 0-20-m [Δ5%], all $p<0.01$), and stable (0-10-m [Δ4%], and 0-

20-m [Δ4%], all $p<0.01$) PT program without any significant difference between groups. The authors concluded that unstable PT does not have any further advantage over PTS for improving speed performance in prepuberal male soccer players. On the whole and in agreement with previous studies (13, 28), eight weeks of either PTS or PTC resulted in similar improvements in sprint-time performance in prepuberal male soccer athletes. Improvements in the 20-m sprint test after PT interventions may primarily stem from transfer effects due to training induced improvements in muscle strength and power. After training, youth athletes are able to generate higher ground reaction forces and faster movement velocities (25). In addition, as long as both PT programs include horizontal jump exercises, this may increase chances of gaining speed adaptations, considering the importance of horizontal force production and application in speed performance (25).

Agility is an important performance determinant in team sports, particularly in soccer (2). Findings of the current study demonstrated similar MICODT improvements after both PT interventions. In previous studies, significant gains on measures of agility have been reported following PT. For instance, Ramirez-Campillo et al. (34) found significant increases in agility (Δ5.1%, $p<0.05$) after 6 weeks of PTS using vertical and horizontal jump exercises in young male soccer players with a mean age of 11.2 ± 2.3 years. Additionally, Negra et al. (26) reported significant improvements in ICODT performance after eight (Δ2%, $p<0.05$) and twelve (Δ3.3%, $p<0.01$) weeks of PTS in prepuberal male soccer players. Likewise, Garcia-Pinillos et al. (12) observed better agility (Δ5%, $p<0.001$) after twelve weeks of contrast training (isometric + plyometric) without external loads in young soccer players with a mean age of 15.9 ± 1.43 years. In the same context, a recent study conducted by Negra et al. (28) demonstrated similar increases in the ICODT test following eight weeks of either stable (Δ3%, $p<0.01$) or unstable PT interventions (Δ3%, $p<0.01$). Likewise, Granacher et al. (13) revealed a significant performance improvement in agility (Δ2.9% to 3.1%, both $p<0.001$) after eight weeks of either stable or unstable PT in sub-elite adolescent male soccer players. The authors concluded that PT on unstable and stable surfaces induced similar effects on agility performance in sub-elite adolescent soccer athletes. In agreement with the previous studies (13, 28), the current results reported similar agility performance improvements in the two experimental groups. This means that both PT programs may have similarly improved both, eccentric and concentric lower limb muscle strength which is an important prerequisite to improving agility (1, 7). In addition, the significant reduction in agility time performance showed that a plyometric program conducted either on stable or combined surfaces can have a positive influence on a field test similar to gameplay and therefore may have an impact on true soccer performance. However, in contrast to our hypothesis, PTC did not have any additive effect on agility performance compared with PTS. In our study, PTC mainly contained horizontal and vertical jump exercises alternated on stable and highly unstable surfaces without performing any rapid change of direction exercises. This lack of training specificity may explain the absence of any extra-effect of PTC on agility. In this context, Young et al. (42) studied the effects of six weeks of sprint versus agility training in healthy and physically active men aged 24 ± 5.7 years and revealed that the agility training group showed significant improvements in agility performance without producing any significant effect on linear sprint performance. Overall, improvements in agility performance may be attributed to neuromuscular adaptations associated with firing frequencies and patterns that enable athletes to rapidly switch between deceleration and acceleration motions (16).

Based on our findings, PTS and PTC have the potential to improve measures of static and dynamic balance. However, only the PTC program induced greater dynamic balance gains at post-test compared with PTS. Of note, Negra et al. (28) recently observed a significant performance enhancement on measures of static balance (Δ121%, 149% for SSBT and USBT, respectively, both $p<0.01$) after eight weeks of PT on unstable surfaces in prepuberal soccer athletes. However, Negra et al. (28) did not find any significant improvements on measures of static balance after the same period of PTS. Yet, in adolescent soccer athletes, Granacher et al. (13) did not detect any significant differences between stable and unstable PT groups with regards to measures of static balance (i.e., one-legged balance). These somewhat contradictory findings seem to be most likely due to differences in the applied training programs. While Granacher et al. (13) conducted mainly vertical jump exercises, we included vertical and horizontal exercises in the present study. In addition, the applied balance tests were different in these studies. Granacher et al. (13) assessed total center of pressure displacements during one legged stance on a force plate. We performed the stork balance test for performance assessment. Finally, subject characteristics were different in the two studies. While Granacher et al. (13) examined adolescent athletes, we studied prepuberal soccer athletes. In summary and with reference to the results of the present study, it is recommended to conduct PTC in youth soccer if the goal is to specifically enhance dynamic balance and other components of physical fitness (e.g., muscle power).

Practical Applications

Findings from the present study illustrated that PTS and PTC applied in conjunction with regular soccer training are safe (i.e., no training-related injuries) and feasible (high [93%] adherence rate) in prepuberal male soccer athletes. In addition, comparable performance improvements were found following both PT interventions on proxies of muscle power, strength, speed, agility, and static balance. However, our findings clearly revealed that PTC generated larger performance improvements in dynamic balance compared with PTS. Therefore, PTC is favored over PTS since it produced similar training effects on components of physical fitness and additional effects on dynamic balance in prepuberal male soccer athletes. Our findings imply that pediatric strength and conditioning coaches may consider giving advantage to PTC over PTS into an overall conditioning program for prepuberal male soccer athletes to promote their physical fitness.

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REFERENCES

1. Asadi, A, Arazi, H, Young, WB, and de Villarreal, SE. The Effects of Plyometric Training on Change-of-Direction Ability: A Meta-Analysis. *Int J Sports Physiol Perform* 11(5):563-73, 2016.
2. Asadi, A, Arazi, H, Ramirez-Campillo, R, Moran, J, and Izquierdo, M. Influence of maturation stage on agility performance gains after plyometric training: A systematic review and meta-analysis. *J Strength Cond Res* May 23, 2017. [Epub ahead of print].
3. Bedoya, AA, Miltenberger, MR, and Lopez, RM. Plyometric Training Effects on Athletic Performance in Youth Soccer Athletes: A Systematic Review. *J Strength Cond Res* 29(8):2351-2360, 2015.
4. Behm, DG, Drinkwater, EJ, Willardson, JM, and Cowley, PM. Canadian society for exercise physiology position stand: The use of instability to train the core in athletic and nonathletic conditioning. *Appl Physiol Nutr Metab* 35 (1): 109-12, 2010.

5. Behm, DG and Colado, *JC*. Instability resistance training across the exercise continuum. *Sports Health* 5 (6): 500-503, 2013.

6. Chaabene, H and Negra, Y. The Effect of Plyometric Training Volume in Prepubertal Male Soccer Players' Athletic Performance. *Int J Sports Physiol Perform* 9: 1-22, 2017.

7. Chaabene, H. Change of Direction Tasks: Does the Eccentric Muscle Contraction Really Matter? Scientific Pages Sports Med 1(1): 1-2, 2017.

8. Cohen J. Statistical Power Analysis for the Behavioural Sciences (2nd ed.). Hillsdale, NJ: Erlbaum Associates 1988.

9. Coppieters, M, Stappaerts, K, Janssens, K, and Jull, G. Reliability of detecting onset of pain and sub-maximal pain during neural provocation testing of the upper quadrant. *Physiother Res Int* 7 (3): 146–156, 2002.

10. Flanagan, EP, Comyns, TM. The use of contact time and the reactive strength index to optimize fast SSC training. *Strength Cond J* 30 (5): 32–38, 2008.

11. Franco-Marquez, F, Rodriguez-Rosell, D, Gonzalez-Suarez, JM, Pareja-Blanco, F, Mora-Custodio, R, Yanez-Garcia, JM, and Gonzalez-Badillo, JJ. Effects of combined resistance training and plyometrics on physical performance in young soccer players. *Int J Sports Med* 36 (11): 906-914, 2015.

12. Garcia-Pinillos, F, Martinez-Amat, A, Hita-Contreras, F, Martinez-Lopez, EJ, and Latorre-Roman, PA. Effects of a contrast training program without external load on vertical jump, kicking speed, sprint, and agility of young soccer players. *J Strength Cond Res* 28 (9): 2452-2460, 2014.

13. Granacher, U, Prieske, O, Majewski, M, Busch, D, and Muehlbauer, T. The Role of Instability with Plyometric Training in Sub-elite Adolescent Soccer Players. *Int J Sports Med* 36(5):386-394, 2015.

14. Hachana, Y, Chaabene, H, Ben Rajeb, G, Khlifa, R, Aouadi, R, Chamari, K, and Gabbett, TJ. Validity and reliability of new agility test among elite and subelite under 14-soccer players. *PloS One* 9(4):e95773, 2014.

15. Hammami, R, Granacher, U, Makhlouf, I, Behm, DG, and Chaouachi, A. Sequencing effects of balance and plyometric training on physical performance in youth soccer athletes. *J Strength Cond Res* 30 (12): 3278-3289, 2016.

16. Hakkinen, K, Alen, M, and Komi, PV. Changes in isometric force and relaxationtime, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand* 125 (4): 573–585, 1985.

17. Kibele, A, Classen, C, Muehlbauer, T, Granacher, U, and Behm, DG. Metastability in plyometric training on unstable surfaces. Sports *Sci Med Rehabil* 17 (6): 30, 2014.

18. Lloyd, RS, Oliver, L, Hughes, M, and Williams, CA. The effetc of 4 weeks of plyometric training on reactive strength index and leg stifness in male youths. *J Strength Cond Res* 26(10): 2812-9, 2012.

19. Malina, RM and Koziel, SM. Validation of maturity offset in a longitudinal sample of Polish boys. *J Sports Sci* 32 (5): 424-437, 2014.

20. Markovic, G and Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Med* 40(10): 859-895, 2010.

21. Matavulj, D, Kukolj, M, Ugarkovic, D, Tihanyi, J, and Jaric, S. Effects of plyometric training on jumping performance in junior basketball players. *J Sports Med Phys Fitness* 41(2): 159-164, 2001

22. Miller, D. Measurement by the Physical Educator: Why and How? Brown and Benchmark, Madison, Wisconsin, USA 2002.

23. Meylan, C and Malatesta, D. Effects of in-season plyometric training within soccer practice on explosive actions of young players. *J Strength Cond Res* 23 (9): 2605-2613, 2009.

24. Michailidis, Y, Fatouros, IG, Primpa, E, Michailidis, C, Avloniti, A, Chatzinikolaou, A, Barbero-Alvarez, JC, Tsoukas, D, Douroudos, II, Draganidis, D, Leontsini, D, Margonis, K, Berberidou, F, and Kambas, A. Plyometrics' trainability in preadolescent soccer athletes. *J Strength Cond Res* 27 (1): 38-49, 2013.

25. Morin, JB, Bourdin, M, Edouard, P, Peyrot, N, Samozino, P, and Lacour, JR. Mechanical determinants of 100-m sprint running performance. *Eur J Appl Physiol* 112 (11): 3921-30, 2012.

26. Negra, Y, Chaabene, H, Stoeggl, T, Hammami, M, Chelly, MS, and Hachana, Y. Effectiveness and time course adaptation of resistance training vs. plyometric training in pre-pubertal soccer players. *J Sport Health Sci* 2016a; in press.

27. Negra, Y, Chaabene, H, M, Hachana, Y, and Granacher, U. Effects of high-velocity resistance training on athletic performance in prepuberal male soccer athletes. *J Strength Cond Res* 30(12):3290-3297, 2016 b

28. Negra, Y, Chaabene, H, Sammoud, S, Bouguezzi, R, Abbes, MA, Hachana, Y, and Granacher, U. Effects of Plyometric Training on Physical Fitness in Prepuberal Soccer Athletes. *Int J Sports Med* ,38(5):370-377, 2017.

29. Nogueira, W, Gentil, P, Mello, SNM, Oliveira, RJ, Bezerra, AJC, and Bottaro, M. Effects of power training on muscle thickness of older men. *Int J Sports Med* 30 (3): 200-204, 2009.

30. Potach and Chu, D. Plyometric training in : Essentials of strength Training and Conditioning-National Strength and Conditioning Association. T Baechle, R Earl, eds. Leed, UK : Hum Kinet pp 427-470, 2000.

31. Prieske, O, Muehlbauer, T, Borde, R, Gube, M, Bruhn, S, Behm, DG, Granacher U. Neuromuscular and athletic performance following core strength training in elite youth soccer: Role of instability. *Scand J Med Sci* Sports 26(1): 48-56, 2016.

32. Ramírez-Campillo, R, Andrade, DC, and Izquierdo, M. Effects of plyometric training volume and training surface on explosive strength. *J Strength Cond Res* 27 (10): 2714-2722, 2013.

33. Ramírez-Campillo, R, Meylan, C, Alvarez, C, Henriquez-Olguin, C, Martinez, C, Canas-Jamett, R, Andrade, DC, and Izquierdo, M. Effects of in-season low-volume high-intensity plyometric training on explosive actions and endurance of young soccer players. *J Strength Cond Res* 28 (5): 1335-1342, 2014.

34. Ramírez-Campillo, R, Gallardo, F, Henriquez-Olguin, C, Meylan, CM, Martinez, C, Alvarez, C, Caniuqueo, A, Cadore, EL, and Izquierdo M. Effect of verti,cal, horizontal, and combined plyometric training on explosive, balance, and endurance performance of young soccer players. *J Strength Cond Res* 29 (7): 1784-1795, 2015.

35. Ramsay, J, Blimkie, C, Smith, K, Garner, S, Macdougall, J, and Sale, D. Strength training effects in prepubescent boys. *Med Sci Sports Exerc* 22 (5): 605–614, 1990.

36. Rodriguez-Rosell, D, Franco-Marquez, F, Pareja-Blanco, F, Mora-Custodio, R, Yanez-Garcia, JM, Gonzalez-Suarez, JM, and Gonzalez-Badillo, JJ. Effects of 6 weeks resistance training combined with plyometric and speed exercises on physical performance of pre-peak-height-velocity soccer players. *Int J Sports Physiol Perform* 11(2): 240-246, 2016.

37. Sekulic, D, Spasic, M, Mirkov, D, Cavar, M, and Sattler, T. Gender-specific influences of balance, speed, and power on agility performance. *J Strength Cond Res* 27(3):802-11, 2013.

38. Sohnlein, Q, Muller, E, and Stoggl, TL. The effect of 16-week plyometric training on explosive actions in early to mid-puberty elite soccer players. *J Strength Cond Res* 28 (8): 2105-2114, 2014.

39. Stolen, T, Chamari, K, Castagna, C, and Wisloff, U. Physiology of soccer: an update. *Sports Med* 35 (6): 501-536, 2005.
40. Voigt, M, Chelli, F, and Frigo C. Changes in the excitability of soleus muscle short latency stretch reflexes during human hopping after 4 weeks of hopping training. *Eur J Appl Physiol Occup Physiol* 78 (6): 522-532, 1998.
41. Weir, JP. Quantifying Test-Retest Reliability using the Intraclass Correlation Coefficient and the SEM. *J Strength Cond Res* 19 (1):231-240, 2005.
42. Young, WB, McDowell, MH, and Scarlett, BJ. Specificity of sprint and agility training methods. *J Strength Cond Res* 15(3):315-9; 2001.

Table 1: Characteristics of the study participants by group.

	PTS (n=17)		PTC (n=16)	
	Pre-test	Post-test	Pre-test	Post-test
Age (years)	12.1 ± 0.5	12.3 ± 0.5	12.2 ± 0.6	12.4 ± 0.6
Body height (cm)	151.6 ± 5.7	153.5 ± 5.8	154.6± 8.1	155.8 ± 7.8
Body mass (kg)	39.2 ± 6.5	39.8 ± 6.9	38.7 ± 5.0	38.8 ± 4.7
Maturity offset	-2.3 ± 0.5	-2.0 ± 0.5	-2.2 ± 0.6	-1.9± 0.7
Predicted APHV	14.4 ± 0.5	14.2 ± 0.4	14.4± 0.5	14.3 ± 0.4

Notes: Data are presented as means and standard deviations (SD); PTS: group that performed plyometric training on stable surfaces; PTC: group that performed combined plyometric training on stable and unstable surfaces; APHV: Age at peak-height-velocity.

Table 2: Progression over 8-weeks of combined plyometric training including stable and unstable surfaces

Week	Plyometric exercises[1]	Volume (sets×reps)	Ground contacts
1	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	4 × 6-7	50
	CMJ on Airex Balance Pad	4 ×6-7	
2	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	4 × 7-8	60
	CMJ on Airex Balance Pad	4 × 7-8	
3	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	4 × 8-9	70
	CMJ on Airex Balance Pad	4 × 9	
4	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	4 × 10	80
	CMJ on Airex Balance Pad	4 × 10	
5	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	4 × 10	90
	CMJ on Airex Balance Pad	6 × 8-9	
6	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	6 × 8-9	100
	CMJ on Airex Balance Pad	6 × 8-9	
7	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	6 × 8	110
	CMJ on Airex Balance Pad	6 × 10	
8	Two footed ankle hop forward (hurdle height: 20 cm), on Thera-Band® stability trainer	6 × 10	120
	CMJ on Airex Balance Pad	6 × 10	

Notes: CMJ: countermovement jump

[1] The combined plyometric training group conducted plyometric exercises on stable and unstable surfaces, while athletes of the stable plyometric training group performed the same exercises on stable surfaces only.

Table 3: Group-specific baseline and post-test performances after eight weeks of in-season plyometric training on components of physical fitness in prepuberal soccer athletes.

	Pre						Post					
	PTS		PTC				PTS		PTC			
	M	SD	M	SD	Diff (95% CI)	*Independent sample t-test* *p*-value	M	SD	M	SD	Diff (95% CI)	*ANCOVA* *p*-value (Cohen's *d*)
Muscle Power												
CMJ (cm)	22.9	3.4	25.3	3.5	2.4 (-4.9 to 0.2)	0.0	26.4	0.6	25.4	0.6	1.0 (-1.1 to 3.0)	0.335 (0.41)
SLJ (cm)	147.7	18.3	159.7	13.6	-5.6 (-23.4 to -0.6)	0.0	166.0	2.4	162.5	2.5	3.4 (-4.8 to 11.7)	0.396 (0.36)
Muscle Strength												
RSI (mm/ms)	1.1	0.3	1.5	0.3	-0.3 (-0.6 to -0.1)	0.0	1.3	0.1	1.1	0.1	0.1 (-0.8 to 0.4)	0.19 (0.57)
Speed												
20-m (s)	3.7	0.1	3.6	0.1	0.1 (-0.0 to -0.2)	0.1	3.5	0.0	3.5	0.0	-0.0 (-0.1 to 0.1)	0.894 (0.06)
Agility												
MICODT (s)	11.9	0.4	11.7	0.3	0.2 (-0.0 to 0.5)	0.1	11.5	0.1	11.6	0.1	-0.1(-0.3 to 0.2)	0.594 (0.23)
Static Balance												
SSBT (s)	4.5	1.9	6.3	3.8	-1.8 (-4.0 to 0.3)	0.1	7.4	0.6	6.9	0.6	0.5 (-1.6 to 2.5)	0.638 (0.20)
Dynamic Balance												
USBT (s)	2.5	1.0	3.3	2.3	-0.8 (-2.1 to 0.4)	0.2	4.1	0.3	5.7	2.8	-1.6 (-2.5 to -0.7)	<0.01 (1.49)

Notes: M: mean; SD: standard deviation; d: Cohen's d (effect size); CMJ: countermovement jump; SLJ: standing long jump; RSI: reactive strength index; MICODT: modified-Illinois change of direction test; SSBT: stable stork balance test; USBT: unstable stork balance test. PTS: group that performed plyometric training on stable surfaces; PTC: group that performed combined plyometric training on stable and unstable surfaces

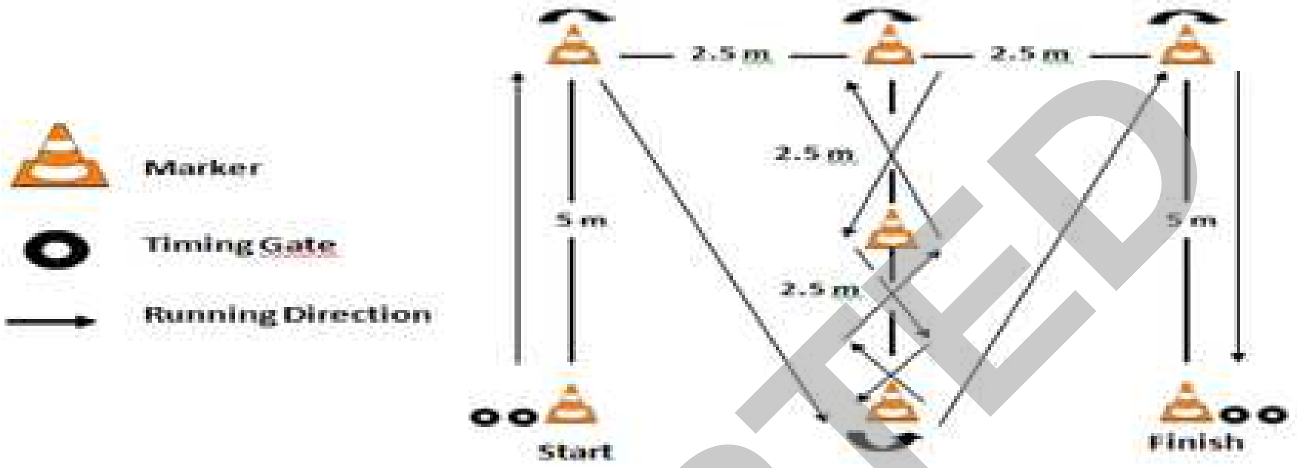

Figure 1 : Layout of the Modified Illinois Change of Direction Test (MICODT).

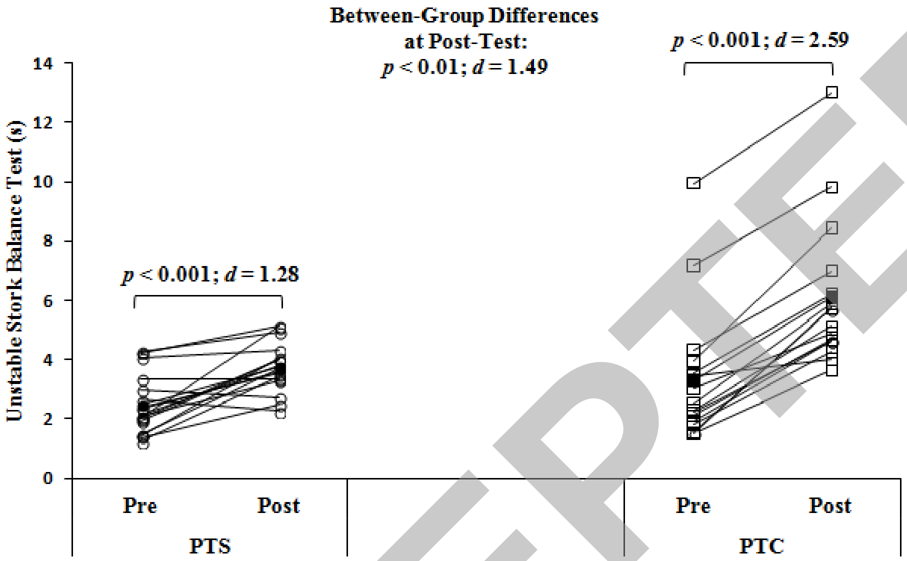

Figure 2: Individual and mean pre- and post-testing data for the unstable stork balance test by intervention group (PTS = group that performed plyometric training on stable surfaces; PTC = group that performed combined plyometric training on stable and unstable surfaces). Unfilled circles indicate individual data and filled circles indicate mean data of the PTS group. Unfilled squares indicate individual data and filled squares indicate mean data of the PTC group.