Effects of high-velocity resistance training on athletic performance in prepuberal male soccer athletes

Running head: Resistance training in prepuberal soccer players

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ABSTRACT

The aim of this study was to assess the effectiveness of 12 weeks in-season low-to-moderate load high-velocity resistance training (HVRT) in addition to soccer training as compared to soccer training only on proxies of athletic performance in prepubertal soccer players. Twenty-four male soccer players performed two different protocols: 1) regular soccer training with five sessions per-week (n=11; age= 12.7±0.3 years); 2) regular soccer training with three sessions per-week and HVRT with two sessions per-week (n=13; age= 12.8±0.2 years). The outcome measures included tests for the assessment of muscle strength (e.g., 1-RM half-squat test), jump ability (e.g., countermovement jump [CMJ], squat jump [SJ] standing long jump [SLJ], and multiple 5 bounds test [MB5]), linear speed (e.g., 5-m, 10-m, 20-m, 30-m sprint test), and change of direction (e.g., T-test, Illinois change of direction test [ICODT]). Results revealed significant group×test interactions for the SJ test ($p<0.05$, $d=0.59$) and the SLJ test ($p<0.01$, $d=0.83$). Post-hoc tests illustrated significant pre post changes in the HVRT group (SJ: $\Delta22\%$, $p<0.001$, $d=1.26$; SLJ: $\Delta15\%$, $p<0.001$, $d=1.30$) but not in the control group. In addition, tendencies towards significant interaction effects were found for the 1-RM half squat ($p=0.08$, $d=0.54$) and the 10-m sprint test ($p=0.06$, $d=0.57$). Significant pre post changes were found for both parameters in the HVRT group only (1-RM: $\Delta25\%$, $p<0.001$, $d=1.23$; 10-m sprint: $\Delta7\%$, $p<0.0001$, $d=1.47$). In summary, in-season low-to-moderate load HVRT conducted in combination with regular soccer training is a safe and feasible intervention that has positive effects on maximal strength, vertical and horizontal jump and sprint performance as compared to soccer training only.

Key words: Youth soccer, change of direction, jump performances, sprint.
INTRODUCTION
Soccer is an intermittent team sport that requires different athletic demands (i.e., adequate levels of muscle strength, power, speed, agility, endurance) for successful performance in competition. It has been shown that muscle actions during rapid movements such as sprinting, jumping, tackling, and change of directions (CoD) have an impact on match performance in youth soccer players (5). In fact, the most decisive moments during the match (i.e., winning ball possession, scoring, conceding goals) are performed during high-speed sprinting (3). Further, high speed sprinting approximates 3% of the total distance covered in youth soccer players’ total match performance (5). Additionally, CoD is an important physical attribute for soccer players, considering the wide range of situations within the game that afford sudden CoD (e.g., tackles) (29). Such actions demand high strength and power generating abilities of the lower limbs (21).

Several scientific reviews and position papers revealed that resistance training (RT) represents a safe and feasible means in healthy children to enhance muscular strength and motor skills, and to prevent sport injuries (2, 3, 12). In their meta-analysis, Falk and Tenenbaum (13) reported strength improvements following 8-20 weeks of RT ranging between 13-30% (effect size [ES] =0.57) in preadolescent children. Results of another meta-analysis conducted by Payne et al. (24) showed even higher ES for children (<13 years) (ES=0.75) compared to adolescents (>16 years) (ES=0.69) indicating larger adaptive potential following RT in the younger age group. In accordance with these results, the meta-analysis of Behringer et al. (4) showed a trend towards higher effect sizes for non-athletes (ES=0.64) compared to youth athletes (ES=0.40). This implies greater training-induced enhancements in levels of motor skills in untrained compared to trained children and adolescents. Within the same study, Behringer et al. (4) reported a negative correlation between the age of the participants and the magnitude of ES indicating that RT is more beneficial in younger participants. This was also shown by Lillegard et al. (19) who demonstrated the highest ES following twelve weeks of RT in pre and early pubertal boys (ES=0.50) compared to pubertal and postpubertal males (ES=0.36).

The question regarding adequate and effective RT protocols is still open for debate in children indicating a gap in the literature. For instance, Faigenbaum et al. (11) demonstrated that in healthy untrained children, one set of high repetition-moderate load RT is more effective to improve muscular strength and endurance than one set of low repetition-heavy load RT. In
accordance with Faigenbaum et al. (11), Behringer et al. (4) suggested that the minimal threshold to elicit enhancements in motor skill performance in children and adolescent lies at around 50% of the one repetition maximum (1-RM). There is evidence in the literature that training-induced gains in muscular strength in children are primarily caused by neural (i.e., improved intra and intermuscular coordination) rather than muscular factors (i.e., muscle hypertrophy) due to a lack of circulating anabolic hormones (i.e., testosterone) (17). In order to optimize training-induced neural adaptations among prepubertal athletes, RT protocols with low to moderate loads and high movement velocities appear to have promising effects due to the specific physiological prerequisites of children and the large adaptive potential of the central nervous system (18). In this context, Granacher et al. (18) studied the effects of an eight week high-velocity and moderate load RT (30-40% 1-RM; 4 sets of 10 repetitions) in high school students and reported significant improvements in maximal isometric force and countermovement jump (CMJ) height.

With reference to the findings of Faigenbaum et al. (11), Behringer et al. (4), and Granacher et al. (17), it appears that RT at low-to-moderate load and high movement velocities might represent an adequate and effective stimulus to induce performance enhancements even in youth athletes. To the authors’ knowledge, there is no study available that examined the benefits of an in-season low-to-moderate load high-velocity resistance training (HVRT) protocol that is conducted in combination with regular soccer training on proxies of athletic performance in prepubertal soccer players. Thus, the purpose of this study was to assess the effectiveness of a twelve week in-season low-to-moderate load HVRT that was performed by replacing two soccer training sessions by two HVRT sessions as compared to soccer training only on measures of muscle strength, power, speed, and CoD, in prepubertal soccer players. We hypothesized that the replacement of soccer specific training sessions by HVRT induces greater strength and power gains in prepubertal soccer players compared to soccer training only.

METHODS

Experimental Approach to the Problem

A two-group repeated measures experimental design was applied to examine the effects of HVRT on proxies of athletic performance in male youth soccer players. A team of experienced soccer players (U-13) was randomly divided into an HVRT group and a control group (CG). The HVRT group conducted three soccer specific training sessions per week and two soccer training sessions were substituted by two HVRT sessions. The CG continued their
regular soccer training with five sessions per week. Pre and post training, tests for the assessment of muscle strength (e.g., 1-RM half-squat test), jump ability (e.g., CMJ, squat jump [SJ] standing long jump [SLJ], and multiple 5 bounds test [MB5] (10)), linear speed (e.g., 5-m, 10-m, 20-m and 30-m sprint test), and CoD (e.g., T-test, Illinois change of direction test [ICODT]) were conducted. All tests were scheduled at least 48 hours after the last training session or match and at the same time of day (7:30-9:30 a.m.), as well as under the same environmental conditions (29-33°C, no wind).

Subjects
Twenty-four healthy players from a regional soccer team were included in the study. They were randomly assigned to the HVRT group (n=13) or CG (n=11). All participants were classified as experienced soccer players with 4.0 ± 1.3 years of systematic soccer training involving three to five training sessions per week. Anthropometric data of both groups are presented in Table 1. Players who missed more than 20% of the total training sessions and/or more than two consecutive sessions were excluded from the study. All participants were free of injuries six months prior to the start of the study and during the course of the study. Maturation status of the participants was determined by the same physician at the beginning and after 12 weeks of training according to the development of pubic hair, based on the Tanner 5-point scale (30) and the predicted age at peak height velocity (20). Prior to the start of the study, all participants and their legal representatives were contacted and informed about testing and training procedures, as well as possible benefits and risks related to the study. Written informed assent (children) / consent (legal representatives) were obtained before the start of the study. The study was approved by the Institutional Review Board of the University of Ksar Said, Tunisia and procedures were in accordance with the latest version of the Declaration of Helsinki.

Table 1 near here

General Testing Procedure
The warm-up program for all tests included 5 min. of sub maximal running with CoD, 10 min. of plyometrics (two sub maximal jump exercises of 20 vertical and 10 horizontal jumps), dynamic stretching exercises, and 5 min. of a sprint-specific warm-up. All tests were separated by a 5-10 min. break in-between. Each player participated in a familiarization trial and two test trials. A rest period of 3 min. was provided between test trials. The best of the
two test trials was used for further analysis. All tests were performed outdoors on an artificial turf pitch with participants wearing their regular training uniform and soccer cleats.

**Maximal Strength Test**

The 1-RM strength test was conducted according to the protocol proposed by Faigenbaum et al. (11). The half squat test was used to determine each subject’s maximal leg extensor strength. The 1-RM was calculated as the maximum weight that could be lifted throughout the full range of motion (90° knee flexion). Before attempting a 1-RM trial, participants performed five to six repetitions at a relatively light load (~40% of their estimated 1-RM). Thereafter, three to four repetitions were performed at a heavier load (~70% of their estimated 1-RM). Finally, a single repetition was conducted with a load corresponding to 95% of the estimated 1-RM. Participants then attempted a single repetition with the perceived 1-RM load. If this load was lifted with proper technique, the load was increased by another 1.0 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 trials with a 2 min. rest between trials. The 1-RM was typically determined within four to five trials. It should be noted that the 1-RM test was conducted every four weeks to adjust the training load in the HVRT group.

**Squat Jump and Countermovement Jump Test**

For the SJ, participants started from a stationary semi-squatted position (knee angle of 90°) and performed a vertical jump at maximal effort. For the CMJ, participants started from an upright standing position, completed a fast downward movement by flexing the knees and hips which was immediately followed by a rapid leg extension resulting in a vertical jump. Throughout the execution of both tests, participants maintained their arms akimbo. CMJ technique was visually controlled by the first author. Performance was recorded using an Optojump photoelectric system (Microgate, SRL, Italy). The ICCs for test-retest trials were 0.97 and 0.96 for the CMJ and SJ, respectively.

**Multiple 5 Bounds Test**

This test has previously been recommended for the measurement of lower limb jumping ability and is considered to be soccer specific (10). From an upright standing position with both feet flat on the ground, participants tried to cover as much distance as possible with five forward jumps by alternating left- and right-leg ground contacts. The covered distance was measured to the nearest 1-cm using a tape measure. The ICC for test-retest trials was 0.96.
Standing Long Jump Test
The starting position required subjects to stand with their feet at shoulders’ width behind a line marked on the ground and their hands in neutral position. On the command ready, set, go, participants executed a countermovement with their legs and arms and jumped at maximal effort in 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 trials was 0.93.

Linear Sprint Test
Thirty-meter linear sprint performance was assessed at 5-m, 10-m, 20-m, and 30-m intervals using an electronic timing system (Microgate SARL, Italy). Participants started in a standing start 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, five single beam photoelectric gates were used. The intraclass ICCs for test-retest trials was 0.96, 0.97, 0.96, and 0.96 for 5-m, 10-m, 20-m and 30-m, respectively.

Change of direction tests
The Illinois change of direction test (ICODT)
The dimensions and route directions for the ICODT were applied in accordance with established methods (1). The ICODT involves placing four markers to indicate an area that is 10-m long and 5-m wide. In the center of the area, four markers were placed 3.3 m apart. The participant started in a prone position with his chin touching the surface of the starting line. The athlete accelerated for 10 m, turned around and returned back to the starting line, and swerved in and out of four markers, completing two 10-m sprints to finish the ICODT 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 (1). The performance outcome was collected using an electronic timing system (Microgate SRL, Italy). The ICC for test-retest trials was 0.94.

The T-Test
This test was administered using the protocol outlined by Munro and Herrington (23). Subjects started with both feet behind the starting line. Four cones were arranged in a T shape, with a cone placed 9.14 m from the starting cone and two further cones placed 4.57 m on either side of the second cone. Each subject accelerated to a cone and touched the base of the
cone with the right hand. Facing forward and without crossing feet, subjects had to shuffle to the left to the next cone and touch its base with the left hand, then shuffle to the right to the next cone and touch its base with the right hand and shuffle back to the left to the last cone and touch its base. Finally, subjects ran backwards as quickly as possible to return to the starting/finish line. The test had to be repeated if athletes crossed one foot in front of the other, failed to touch the base of the cone and/or failed to face forward throughout the test. The time needed to complete the test was used as performance outcome and it was assessed with an electronic timing system (Microgate SARL, Italy). The ICC for test-retest trials was 0.90.

**Soccer Training Protocol**

The CG participated in a regular soccer training program over the twelve-week intervention period with five training sessions per week lasting between 80 and 90 min. each. The HVRT group participated in three soccer specific training sessions per week which were similar to those of the CG and two HVRT sessions so that the overall exposition 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.

**High-Velocity Resistance Training**

The HVRT program was conducted during the in-season period. Prior to every HVRT session, a standardized 8-12 min. warm-up was completed that included low intensity running, coordination exercises, dynamic movements (i.e., lunges, skips), sprints, and dynamic stretching for the lower limb muscles. Each HVRT session lasted between 80 and 90 min. At the beginning of each training week, the first HVRT session was performed at least 48 hours after the soccer match that was scheduled on the weekend. More specifically, soccer matches were mostly organized on Saturday mornings. Therefore, HVRT started on Monday mornings. The second HVRT session was completed 72 h after the first session (mostly Thursday mornings). The HVRT program consisted of half squat exercises with 4 sets of 8 to 12 repetitions and a 2 min. rest between sets. Training load was adjusted and increased over the course of the training. During the first week, subjects exercised at 40% of their 1-RM. During the second week, the load was increased to 50% 1-RM and during the third week to 60% 1-RM. During the fourth week of training, the load was decreased to 40% 1-RM to avoid
overtraining and to allow adaptation. This 3:1 cycle was applied three times over the twelve-week training period. Participants were instructed to perform each half squat repetition as fast as possible with a break of approximately 2 s between repetitions. In addition to the HVRT exercises for the leg extensors/flexors, participants performed abdominal curl and back extension exercises in every session with 6 sets of 15 repetitions. These core exercises were included to provide a general conditioning effect as suggested in the position stand of Behm et al. (3). The HVRT program was supervised by a qualified instructor certified by the Tunisian soccer association.

Statistical Analyses
Data are presented as means and standard deviations (SD). Data were tested for normal distribution using the Shapiro-Wilk’s test. An independent samples t-test was applied to determine significant differences in baseline values between groups. Subsequently, a 2 (group: HVRT, CG) × 2 (test: pre, post) analysis of variance with repeated measures on test was used to identify the effects of HVRT as compared to CG over time. When group x test interactions reached the level of significance, group-specific post-hoc tests (i.e., paired t-tests) were computed to identify the comparisons that were statistically significant. Additionally, the classification of effect sizes (ES) was determined by converting partial eta-squared to Cohen’s d. The ES is a measure of the effectiveness of a treatment and it helps to determine whether a statistically significant difference is, really, a difference of practical concern. According to Cohen (9), 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 intraclass correlation coefficients (ICCs) (9). The alpha level of significance was set at $p < 0.05$. All data analyses were performed using SPSS 19.0 (SPSS, Inc, Chicago, IL, USA).

RESULTS
All subjects of the HVRT group and CG group received treatments as allocated. During the intervention period, one subject in the HVRT group dropped out because he left the youth soccer training center. Another subject in the CG discontinued the intervention because of personal reasons. Thus, 24 participants completed the training program and none reported any training or test related injury. Table 3 displays means and SDs for all analyzed variables. There were no statistically significant differences in baseline values between the two groups. In addition, no significant differences were found between both groups with regards to chronological age, height, body mass, stages of puberty development by Tanner (30), age at peak height velocity (APHV), and soccer experience, suggesting that: a) boys were all in pre
pubertal period, and b) both groups had similar age and anthropometric characteristics (Table 1).

**Effects of High-Velocity Resistance Training**

**Maximal Strength Test**

Values for all variables at baseline and post intervention are presented in Table 3. The statistical analysis revealed a significant main effect of test \( (p < 0.01, d = 0.87) \) and a tendency towards a significant group × test interaction for the 1-RM half squat test \( (p = 0.08, d = 0.54) \). Post-hoc analysis showed significant increases in half squat performance from pre to post-test in the HVRT group only \( (Δ25\%, p < 0.001, d = 1.23) \).

**Vertical Jump Tests**

A significant main effect of test was found for both, the CMJ \( (p < 0.001, d = 1.17) \) and the SJ \( (p < 0.01, d = 0.91) \). A significant group × test interaction was detected for the SJ test only \( (p < 0.05, d = 0.59) \). Post-hoc analysis showed significant increases in SJ performance from pre to post in the HVRT group only \( (Δ22\%, p < 0.001, d = 1.26) \) (Table 3).

**Horizontal Jump Tests**

A significant main effect of test was established for the SLJ test \( (p < 0.01; d = 0.80) \) and a significant group × test interaction \( (p < 0.01; d = 0.83) \). Post-hoc analysis revealed a significant increase in SLJ from pre to post-training in the HVRT group only \( (Δ15\%, p < 0.001, d = 1.30) \). No significant main effect of test \( (p > 0.05, d = 0.45) \) and group × test interaction \( (p > 0.05, d = 0.49) \) were found for the MB5 test.

**Linear Sprint Test**

Statistical results revealed a significant main effect of test for all sprint intervals (0-5m, 0-10m, 0-20m and 0-30m sprint) and a trend towards a significant group × test interaction for the 10-m sprint interval only \( (p = 0.06, d = 0.57) \). Post-hoc analysis showed significant increases in 10-m sprint performance from pre to post-test in the HVRT group only \( (Δ7\%, p < 0.0001, d = 1.47) \). However, group × test interaction failed to reach the significance level for all sprint intervals \( (p > 0.05, d= 0.24-0.48) \) [Table 3]).

**Change of direction tests**

In view of the CoD tests, significant main effects of test were found for the ICODT \( (p < 0.02, d = 0.71) \) and the T-test \( (p < 0.01, d = 0.77) \). In addition, no significant group × test interactions were observed for both tests \( (all p > 0.05, d = 0.24 \text{[ICODT]}, d = 0.40 \text{[T-test]}) \).
DISCUSSION

The main objective of the current study was to examine the effects of in-season low-to-moderate load HVRT conducted in combination with regular soccer training as compared to soccer training only on measures of muscle strength, power, speed, and change of direction (CoD) in prepuberal male soccer players. The main results of this study were that: (1) HVRT in combination with regular soccer training is a safe (i.e., no RT related injuries) and feasible intervention in youth soccer players, and (2) greater performance improvements were observed in the intervention as opposed to the CG over time in SJ and SLJ performance, and a tendency towards a greater improvement in 1-RM half squat and 10-m sprint test.

Effects of resistance training on maximal strength

Findings from this study revealed training-induced improvements in 1-RM half squat following twelve weeks of HVRT. This is in agreement with previous investigations that observed increases in strength performance after HVRT intervention. For instance, Taube et al. (31) demonstrated significant increases in maximal isometric leg extensor strength after six weeks of HVRT (60% of 1-RM, 4-6 sets of 12 repetitions, 3 times / week) in pubertal elite athletes with a mean age of 14.5 ± 1 year. In the same context, Granacher et al. (18) reported a significant performance enhancement in maximal isometric leg extension force (Δ17%; ES = 0.56) after eight weeks of HVRT for the lower extremities (30-40% 1-RM, 4 sets of 10 repetitions, 2 times / week) in high-school students aged 16.7 ± 0.6 years. Further, Muehlbauer et al. (22) studied the effects of eight weeks of lower extremity HVRT (30-40% 1-RM, 4-6 sets of 10 repetitions, 2 times / week) in female and male high-school students aged 16-17 years and showed a significant improvement in relative and absolute maximal isometric force of the leg extensor muscles in females (ES = 1.85) but not in males (ES = 0.89). They attributed this finding to the lower adaptive reserve in males compared with females. In another study, Shaibi et al. (27) revealed that sixteen weeks of lower extremity high intensity RT (62-97% 1-RM, 1-3 sets of 3-15 repetitions, 2 times / week) induced significant gains in 1-RM leg extensor strength (Δ28%, ES = 0.85) in adolescent males with a mean age of 15±1 years. Christou et al. (7) studied the effects of sixteen weeks of RT for the lower/upper extremities (55-80% 1-RM, 2-3 sets of 8-15 repetitions, 2 times / week) in adolescent soccer players (13.8±0.4 years) and observed significant gains in 1-RM leg press
performance after eight (Δ38%, ES = 1.73) and sixteen weeks (59%, ES = 2.77). The observed wide range of values in terms of training-induced effects and/or level of change expressed in percentage between the current study (Δ25%, ES = 1.23) and the aforementioned studies (7, 27, 31) may be attributed to differences in the applied training modalities (e.g., training duration, frequency and intensity) and/or factors like biological/chronological age, training experience, sex that may interfere with the effects of HVRT in conjunction with regular soccer training.

Effects of resistance training on vertical and horizontal jump performance

In the present study, HVRT induced significant improvements in measures of vertical and horizontal jump performance which is in agreement with previous research (7, 17, 22). For instance, Christou et al. (7) revealed significant improvements in SJ and CMJ height after eight (SJ: Δ13%, ES = 0.76; CMJ: Δ14%, ES = 0.86) and sixteen weeks (SJ: Δ31%, ES = 1.65; CMJ: Δ25%, ES = 1.49) of lower/upper extremities RT in adolescent soccer players with a mean age of 14 ± 0.4 years. In agreement with the findings of Christou et al. (7), Taube et al. (31) observed increases in CMJ height after six weeks of HVRT in pubertal elite athletes (mean age 14 ± 1 year). In the same context, Granacher et al. (18) reported significant increases in CMJ height after eight weeks of HVRT in adolescents (Δ8%; ES = 0.75). In a meta-analyses, Behringer et al. (4) revealed that a structured RT intervention significantly enhances jumping performance in children and adolescents (ES = 0.54). In addition, Muehlbauer et al. (22) reported significant improvements in CMJ height in girls (Δ8%; ES = 1.37) and boys (Δ7%; ES = 0.61) following eight weeks of HVRT. Rodriguez-Rosell et al. (25) reported a moderate improvement in CMJ height (Δ12%; ES = 0.71) in the intervention group after six weeks of combined RT (45-60% 1-RM, 2-3 sets of 4-8 repetitions, 2 times / week) with plyometrics in prepubertal soccer players with a mean age of 13±0.5 years. Recently, Franco-Marquez et al. (14) studied the effects of six weeks of combined RT (45-58% 1-RM, 2-3 sets of 4-8 repetitions, 2 times / week) with plyometrics in post-pubertal soccer players (age 15±0.5 years) added to their regular technical-tactical training. These authors extended the previously presented findings and reported significant improvements in CMJ height (Δ9%; ES = 0.58). In line with these scientific findings, our results illustrate that prepubertal soccer players can largely increase their vertical (ES= 1.26) and horizontal (ES = 1.30) jump performance by means of a low frequency (i.e., two sessions per-week) and low-to-moderate load (i.e., 40-60% 1-RM) HVRT program in addition to their standard soccer training program. It is worth noting that the higher ES established in this study is indicative of
a larger HVRT effect compared to those training protocols applied in previous research (4, 7, 14, 18, 22, 25). Therefore, our HVRT program appears to be effective if the goal is to improve vertical and horizontal jump performance of prepubertal soccer players. It might be speculated from the applied RT intervention that the marked improvements in both jumping tests could mainly be caused by neural adaptations (17). In fact, Taube et al. (31) argued that HVRT increased activation of lower extremity muscles through enhanced motor unit activation and improved intermuscular coordination in conjunction with decreased co-activation of antagonistic muscles (6, 8).

**Effects of resistance training on sprint performance**

Our findings demonstrated increases in all sprint tests after twelve weeks of HVRT (5-m [Δ-7%, ES = 1.04]; 10-m [Δ-7%, ES = 1.47]; 20-m [Δ-5%, ES = 0.84] and 30-m [Δ-4%, ES = 0.68]). Results from previous studies (7) revealed a significant improvement in 30-m sprint test (Δ-2%, ES = -0.3) after sixteen weeks of RT in adolescent soccer players with a mean age of 14±0.4 years. Rodriguez-Rosell et al. (25) showed a clear improvement in sprint performance after six weeks of combined RT and plyometrics in prepubertal soccer players (10-m [Δ-3%; ES = 0.78]; 10-20-m [Δ-3%; ES = -0.82]; and 20-m [Δ-3%; ES = -0.75]). The meta-analysis of Rumpf et al. (26) illustrates the effects of combined RT and plyometrics in pre-PHV participants and reported significant gains in sprint performance (Δ-3%, ES = 0.52). In another meta-analysis, Behringer et al. (4) aggregated findings from 34 studies and demonstrated medium effects (ES = 0.53) of RT in children on running performance (e.g., 30-m sprint time). The recent study of Franco-Marquez et al. (14) in post-pubertal soccer players showed that combined RT with plyometrics improved significantly 20-m sprint performance (Δ-1%; ES = 0.29). In summary, these studies highlight the positive effects of different types of RT on sprint performance in prepubertal athletes. In view of the higher ES established in the present study compared to the aforementioned investigations, low-to-moderate load HVRT seems to be more effective in increasing sprint performance in prepubertal soccer players compared to combined RT and plyometrics (25, 26). The observed increases in sprint performance following HVRT are most likely caused by increases in neuromuscular activation of the trained muscles. More specifically, increases in number and/or firing frequencies of active motor units and/or changes in the recruitment pattern of the motor units, primarily of fast-twitch muscle fibers might account for the observed results (15, 29).
Effects of resistance training on change of direction

With regards to CoD performance, the present study showed significant performance improvements in the HVRT group with no significant pre-post changes in the CG. CoD improvement observed through ICODT and the T-test was 4% and 5%, respectively when compared to baseline assessment. This is consistent with the findings of Garcia-Pinillos et al. (16) who studied the effects of twelve weeks contrast training (isometric + plyometric) without external load (4-6 sets with 1-6 repetitions, 2 times / week) on CoD performance in young soccer players aged 15.5 ± 1.3 years. The authors reported a significant improvement in the Balsom agility test amounting to 5%. Christou et al. (7) showed an improvement in the 10×5-m shuttle run agility test of about 3% (ES = -0.83) after eight weeks and 5% (ES = -1.74) after sixteen weeks RT program within adolescent soccer players (13.8±0.4 years). This means that RT program may have improved both, eccentric and concentric lower limb muscle strength which is an important prerequisite to improve change of direction movements (28). Overall, improvements in CoD after RT intervention can be attributed to neural adaptation. Thus, HVRT seems to constitute a good RT alternative in prepubertal soccer players for the development of their CoD skills.

Some methodological limitations related to the current study warrant discussion. First, no additional analyses or tests were conducted to establish whether the HVRT program resulted in a true positive adaptation with regards to match performance. We can only speculate that greater performance in the applied tests may have resulted in higher match-play performance. Second, the current study did not quantify neuromuscular changes following HVRT and no ground reaction forces were collected during jump and sprint performances. Biomechanical and electrophysiological testing methods should be implemented in future studies to obtain in-depths knowledge regarding adaptative processes following HVRT in prepubertal soccer players.

PRACTICAL APPLICATION

Results obtained from the present study revealed that HVRT conducted in conjunction with regular soccer training is safe (i.e., no injuries occurred) and feasible (two training sessions per-week) in prepubertal soccer players. In addition, our findings imply that prepubertal soccer players may benefit from an in-season low-to-moderate load HVRT program that is conducted in addition to regular soccer training by increasing their athletic performance.
Notably, larger improvements were found in the HVRT as compared to the CG in vertical and horizontal jumping performance. In addition, a trend towards higher increases was observed in maximal strength and linear sprint performance in favor of the HVRT group. These findings imply that if the goal is to improve proxies of athletic performance, HVRT appears to be a well-suited and beneficial program. These outcomes have several implications for coaches and exercise scientists because they could help optimize daily training routines so as to produce greater increases in tasks critical to soccer performance in prepubertal athletes. This study focused on performance effects of HVRT only. Future studies should examine age- and sex-specific effects of HVRT on measures of physical fitness and additionally scrutinize the underlying neuromuscular adaptations following short- and long-term HVRT in youth soccer players.
REFERENCES


**ACKNOWLEDGMENT**

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**Table 1:** Anthropometric data of the included subjects.

<table>
<thead>
<tr>
<th></th>
<th>CG (n=11)</th>
<th></th>
<th>HVRT (n=13)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
<tr>
<td>Age (years)</td>
<td>12.74 ± 0.26</td>
<td>12.97 ± 0.26</td>
<td>12.80 ± 0.25</td>
<td>13.03 ± 0.25</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>154.52 ± 11.12</td>
<td>155.0 ± 11.32</td>
<td>160.43 ± 9.06</td>
<td>161.16 ± 8.56</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>45.39 ± 8.08</td>
<td>46.02 ± 8.93</td>
<td>49.17 ± 8.09</td>
<td>50.39 ± 8.62</td>
</tr>
<tr>
<td>Tanner score</td>
<td>1.91 ± 0.7</td>
<td>2.0 ± 0.77</td>
<td>1.77 ± 0.73</td>
<td>1.85 ± 0.69</td>
</tr>
<tr>
<td>Maturity Offset</td>
<td>-1.52 ± 0.79</td>
<td>-1.38 ± 0.81</td>
<td>-1.24 ± 0.82</td>
<td>-1.04 ± 0.71</td>
</tr>
<tr>
<td>APHV</td>
<td>14.26 ± 0.88</td>
<td>14.35 ± 0.93</td>
<td>14.04 ± 0.83</td>
<td>14.07 ± 0.72</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD; CG: Control group; HVRT: High velocity resistance training; APHV: Age at peak height velocity.
Table 2: Athletes training characteristics during the twelve week intervention period

<table>
<thead>
<tr>
<th></th>
<th>CG (n=11)</th>
<th>HVRT (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of training sessions</td>
<td>73</td>
<td>75</td>
</tr>
<tr>
<td>Number of matches</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Number of HVRT sessions</td>
<td>0</td>
<td>24</td>
</tr>
</tbody>
</table>

CG: control group, HVRT: High velocity resistance training group.
Table 3: Effects of twelve weeks high-velocity resistance training on proxies of athletic performance in prepuberal soccer players.

<table>
<thead>
<tr>
<th></th>
<th>CG (n=11)</th>
<th>HVRT (n=13)</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>MB5 (m)</td>
<td>8.73</td>
<td>0.62</td>
<td>8.71</td>
</tr>
<tr>
<td>SLJ (m)</td>
<td>1.58</td>
<td>0.13</td>
<td>1.57</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>21.13</td>
<td>2.96</td>
<td>23.75</td>
</tr>
<tr>
<td>SJ (cm)</td>
<td>19.06</td>
<td>2.29</td>
<td>20.10</td>
</tr>
<tr>
<td>1-RM Half squat</td>
<td>83.82</td>
<td>18.3</td>
<td>90.00</td>
</tr>
<tr>
<td>5-m sprint (s)</td>
<td>1.21</td>
<td>0.08</td>
<td>1.20</td>
</tr>
<tr>
<td>10-m sprint (s)</td>
<td>2.13</td>
<td>0.10</td>
<td>2.09</td>
</tr>
<tr>
<td>20-m sprint(s)</td>
<td>3.74</td>
<td>0.18</td>
<td>3.68</td>
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<tr>
<td>30-m sprint (s)</td>
<td>5.32</td>
<td>0.22</td>
<td>5.23</td>
</tr>
<tr>
<td>ICODT (s)</td>
<td>17.73</td>
<td>0.36</td>
<td>17.56</td>
</tr>
<tr>
<td>T-test(s)</td>
<td>11.73</td>
<td>0.59</td>
<td>11.54</td>
</tr>
</tbody>
</table>

Notes: M: mean; SD: standard deviation; MB5: multiple five bounds test; SLJ: Standing Long jump Test; CMJ: Countermovement jump; SJ: Squat jump test; ICODT: Illinois change of direction test; d: Cohen’s d (effect size).