Carlos-Vivas, J., Perez-Gomez, J., Eriksrud, O., Freitas, T., Marín-Cascales, E., Alcaraz, P. E. (2020). Vertical Versus Horizontal Resisted Sprint Training Applied to Young Soccer Players: Effects on Physical Performance. *International Journal of Sports Physiology and Performance (IJSPP), 15*(5), 748-758. 10.1123/ijspp.2019-0355

Title: Does the load direction (vertical vs horizontal) of resisted sprint training affect performance adaptations in soccer?

Preferred running head: 8-week resisted sprint training in soccer

Authors and Affiliations:

Jorge Carlos-Vivas[1]; Jorge Perez-Gomez[2]; Ola Eriksrud[3]; Tomás T. Freitas[1], Elena Marín-Cascales[1], Pedro E. Alcaraz[1,4]

[1]UCAM Research Center for High Performance Sport, Catholic University of Murcia, Murcia, Spain.

[2]Health, Economy, Motricity and Education Research Group, Faculty of Sport Sciences, University of Extremadura, Caceres, Spain.

[3]Department of Physical Performance, Norwegian School of Sports of Science, Oslo, Norway.

[4]Faculty of Sport Sciences, UCAM, Catholic University of Murcia, Murcia, Spain.

Corresponding Author:

Name: Pedro E. Alcaraz Ramón

Affiliation/Institution: UCAM Research Center for High Performance Sport, Catholic University of Murcia, Murcia, Spain

Mail address: Campus de los Jerónimos, nº 135. 30107. Guadalupe, Murcia (Spain).

Telephone number: (+34) 968 278 566

E-mail address: palcaraz@ucam.edu

ACKNOWLEDGEMENTS

We would like to thank 1080 Motion AB for providing the 1080 Sprint™ device for this project. Likewise, we would like to acknowledge the coaching staff and players from the teams involved in the research for their collaboration. In addition, we would like to thank the International Doctoral School of the Catholic University of Murcia (EIDUCAM) for the predoctoral scholarship. This research is supported by a grant by the Spanish Ministry of Economy and Competitiveness (DEP2011-28727).

DOES THE LOAD DIRECTION (VERTICAL VS HORIZONTAL) OF RESISTED SPRINT TRAINING AFFECT PERFORMANCE ADAPTATIONS IN SOCCER?

ABSTRACT

To analyse and compare the effects of four different resisted sprint training (RST) modalities on youth soccer players' performance after 8 weeks of training. Forty-eight youth soccer players (18.3 ± 2.1 years) completed 8 weeks of RST and were randomly assigned to 4 groups: horizontal resisted sprint (HRS), vertical resisted sprint (VRS), combined resisted sprint (CRS) and unresisted sprint (URS). The performance on horizontal and vertical jump, sprint and change-of-direction ability (COD) were assessed one week before and after the training intervention. Magnitude-based inferences (MBI) analysis was performed for calculating within-groups pre-post differences. Additionally, an ANCOVA test was performed for between-group comparison, using the pre-test values as covariates. After that, the ANCOVA p-values and the effect statistic was transformed to MBI. Within-group outcomes showed that all resisted training modalities experienced improvements in sprint (*small to moderate*) and COD (*small to large*) performance. Moreover, all groups, except URS, enhanced the horizontal jump performance. However, only VRS improved on vertical jump. Between-group comparison outcomes revealed that only VRS improved the sprint time compared to HRS (*moderate*) and COD performance compared to all groups (*moderate to large*). Additionally, VRS enhanced the countermovement jump (CMJ) performance (*small to large*) compared to the other groups. Independently of the orientation of the resistance applied, RST is an effective training method for improving sprinting and COD performance. Nevertheless, VRS may promote greater improvements on sprint and COD ability, and have a positive additional effect on CMJ performance and the reduction of COD deficit.

Keywords: agility, cutting, football, ground reaction forces, power, speed

INTRODUCTION

Straight sprinting, change-of-direction (COD) and jumps are fundamental qualities to soccer performance which are presented in common actions such as, when scoring a goal, assisting to a teammate or anticipating opponents' behaviour[1]. A soccer player performs hundreds of CODs during a match[2], most of them being initiated at low velocities and followed by a linear sprint. Specifically, the most typical high-intensity action is a 100-120 degrees COD, immediately followed by a 5-20 m linear sprint[2]. Thus, COD ability is partially related to the straight sprinting ability and depends on both horizontal and vertical propulsive forces[3]. In fact, athletes who produce greater vertical and horizontal propulsive forces obtain a better performance in COD tasks. Moreover, these athletes showed greater vertical and horizontal braking forces, hip abduction and knee flexion angle[4]. Stølen et al.[5] claimed that well-developed strength in lower limbs is important for soccer players, as this basic capability influences power performance and the success in high-intensity skills, which play a key role in team sports, such as soccer. Therefore, power and speed training are crucial in order to be success in decisive situations in soccer.

In order to develop these qualities, MacDougall and Sale[6] argued that training should be specific with regard to movement pattern, applied force, muscle activation type, and contraction velocity. This means that RST provides a specific stimulus to athlete[7] which leads to positive adaptations, by increments on neural activation[8,9] or the overload in hip extensors[10]. Thus, not surprising that training routines in soccer include training methods which involve specific motor tasks, such as resisted sprinting or plyometrics. In this regard, resisted sprint training (RST), where athletes sprint with an added overload, has been shown as an effective training method for enhancing athletes' performance[7,11-14]. Additionally, RST modalities may also produce a positive effect on COD ability, and consequently, improve the athlete´s performance. A few previous studies have analysed the effects of low-load[15,16] and heavy-load[17] RST programs on soccer players with reported improvements in COD performance, but not better than unresisted sprint training (URS)[16] or other training programs, such as squat training or plyometrics[15]. More recently, Rodriguez-Osorio et al.[18] concluded that 6 weeks of RST with COD without extra-load and using moderate (12.5% body mass) and heavy loads (50% body mass) may have positive effects on sprinting, COD, and jumping performance, especially using moderate loads.

There are different RST modalities depending on the direction of load (i.e. sled, weighted vest, and parachute)[19-21] commonly utilized by coaches and practitioners. Regarding the direction of force application, it is clear that the development of large forces is a key quality for inducing neuromuscular adaptations[22] and functional enhancements of athletic tasks[23]. However, coaches and practitioners must take into account that performance also depends on the ability to apply such forces at a specific rate, and with an orientation similar to that required by the mechanical demands of the task[6,24]. In this regard, an important difference between the RST modalities, which may affect the adaptations induced to the athlete, is the orientation of the resistance applied[19]. In fact, recent studies showed that chronic performance (i.e. sprinting, jumping…) and biomechanical adaptations (i.e. effectiveness of applied force, stiffness…) may be associated with vertically and/or horizontally-oriented training programmes[25-27]. Thus, the direction of the resultant GRF vector, related to the force applied by the athlete, will differ according to the conditions in which the force is applied[28]. Therefore, depending on the exercise, the work should focus more on the application of vertical or horizontal forces. For instance, previous studies on sprinting showed that horizontal forces were higher at the first steps during the acceleration phase, while vertical forces gradually took greater importance as velocity increased[29-31]. Nevertheless, these studies were performed on sprinters using starting blocks, which in team-sports, such as soccer, is different because sprinting starts from a more upright position and while in motion[32].

In this regard, due to the interest generated by the requirement of accelerating an athlete's body in many sports, the ground reaction forces (GRF) have been largely studied in the scientific literature[29-31,33,34]. Recently, Colyer et al.[33] showed that sprinters produced higher average horizontal power than soccer players, which allows them to accelerate more time and beyond the velocity plateau of the soccer players. Therefore, it is well known that higher average anteroposterior force production across the acceleration phase and the ability to maintain a more horizontally-orientated force vector as velocity increases are crucial performance indicators[31,35]. Considering that resisted sled training focus on the development of horizontal forces, many studies have focused on determining the chronic adaptations of RST using a sled. A recent meta-analysis by Alcaraz et al.[7] performed a synthesis of them, establishing that RST using sled is effective for improving the acceleration phase of sprint, where the horizontal component GRF is key, but not for the maximum-velocity phase. However, when running at higher relative speeds the force vector is more vertical, with the limiting factor for maximum velocity being the ability to exert high vertical normalized force (body mass) with short ground contacts[34]. Thus, Cronin et al.[21] suggested that RST wearing a weighted vest, vertically-oriented resistance, may be a more appropriate resistance modality than sled, which is a horizontally-oriented resistance, at high velocities. In fact, it has been shown that the transition from lower to higher velocities results in shorter support phase duration with simultaneous increases in vertical peak force[36] producing large vertical forces which are associated with better sprint performances[30]. However, there are no studies which have investigated the adaptations produced by RST intervention using equipment which provide the athletes vertically-oriented resistances, such as weighted vest; moreover, the weighted vest has the advantage of performing COD, which is also crucial in soccer, compared to sled.

All aforementioned suggests that both vertically- and horizontally-oriented RST, as the combination of both, may have great effects on soccer players' performance. Therefore, the aim of the study was to analyse and compare the effects of different RST modalities on youth soccer players' performance after 8 weeks of linear and COD sprinting. Based on the findings of previous researches, we hypothesized: 1) all RST groups will experience improvements in sprint and COD performance, and they will also likely obtain enhancements in horizontal and vertical jump; 2) the groups that performed RST with an added horizontally or vertically-oriented overload will achieve the greatest improvements in horizontal and vertical-oriented exercises, respectively.

METHODS

Participants

Sixty active healthy male youth soccer players were recruited with forty-eight (age: 18.3 ± 2.1 years; height: 1.78 ± 0.05 m; weight: 72.7 ± 9.5 kg) completing the study. Twelve players dropped out of the study for the following reasons: unable to complete 90% of training sessions (n=5), suffered an adverse event (n=1) or lower limb injury (n=2), or promoted to a higher level team (n=4). All of the players had previous experience in RST. Inclusion criteria were no injuries in the past six months that limited sports participation for more than seven days or undergoing rehabilitation in the last six months and no medical condition preventing maximal exertion. Participants were informed about the experimental procedures, possible risks, and the benefits associated with participation before signing the consent form prior to testing. The study was carried out in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee.

Design

A randomized pre-post 10-week experimental study was performed: 1-week pre-testing, 8 weeks of RST and 1-week post-testing. Normal team practice and competition schedule, consisting of 3 training sessions and 1 match per week, were maintained during the investigation period. To document the internal training load, the rating of perceived exertion[37] was taken at the end of each training. The results show that there were no between-group differences in the internal training load (*P*=0.853). All players performed these training sessions under the guidelines of the same coach.

Following inclusion into the study, players were randomly assigned to one of four groups, using the computer software Research Randomizer (Version 4.0) (http://www.randomizer.org): vertical resisted sprint (VRS; n=11), horizontal resisted sprint (HRS; n=13), combined resisted sprint (CRS; n=12) and unresisted sprint (URS; n=12).

Training program. All training groups performed the same RST protocol twice a week in none consecutive days (MD-4 and MD-2) during a total of 8 weeks (16 sessions). The main difference between groups was the equipment used as resistance during the RST program, and consequently, the direction of the resistance applied: VRS wore a weighted vest (GetStrong, Get Strong Fitness S.L., Ávila, Spain), HRS towed a portable robotic resistance device (1080 Sprint™, 1080 Motion, Lidingö, Sweden) featuring a servo motor (2000 RPM OMRON G5 Series Motor, OMORON Corporation, Kyoto, Japan) attached on the waist, CRS combined both equipments (weighted vest and 1080 Sprint™), and URS performed the same training protocol without added resistance. The training program followed an undulating periodization, combining linear sprinting sessions (8 sessions) and COD sessions (8 sessions), which consisted of slalom sprinting with 100° COD each 5-m section until cover 20 m. The maximum extra-load was 20% of body mass (BM), independent of equipment used, based on previous sled[7] and weighted vest[20] recommendations. Horizontal load was prescribed using the 1080 Sprint™ (isotonic resistance mode) based on an estimated friction coefficient of 0.35. Specifically, the absolute load (% BM) was multiplied by this factor to determine horizontal load. Therefore, the absolute load should be multiplied by 0.35 to get the similar load on a sled. All training sessions were supervised by the principal investigator. The RST protocol was performed at the beginning of the training sessions, after warming up. The full training protocol is described in table 1.

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

The independent variable was the training program, and the dependent variables were standing long jump distance ($SLJ_{Distance}$), maximum countermovement jump power (CMJ_{Pmax}) and height (CMJ_{Height}), sprint time at 30-m ($T_{0\text{-}30m}$), 0-10m ($T_{0\text{-}10m}$), 10-20m ($T_{10\text{-}20m}$) and 20-30m ($T_{20\text{-}30m}$), maximum sprint velocity (V_{max}), maximum theoretical velocity (V_0), theoretical maximal horizontal force (F_0), maximum horizontal sprint power output (P_{max}), the effectiveness of force application, which is determined by the maximum ratio of the step-averaged horizontal component of the GRF to the corresponding resultant force for sprint times over >0.3 seconds (RF_{max}) and the rate of decrease in RF (D_{RF}), COD in time (COD_{Time}), speed (COD_{Speed}) and deficit ($COD_{Deficit}$).

Methodology

Testing was conducted in-season, after 2 days of rest, to limit the influence of fatigue. Players wore their own athletic gear during the tests: training clothes and soccer boots. Before starting the testing, all players performed a standardized specific warm-up, consisting of 8-min low-intensity running, 7-min active dynamic stretching, 3 to 4 submaximal vertical jumps and 3 to 4 submaximal to maximal 30-m sprints with a 90-s rest between trials. Afterwards, all players performed the tests in the following order: SLJ, CMJ, 30-m sprint and COD with 10-min rest between tests. All tests were performed on an outdoor artificial turf 3G soccer field, except for the CMJ test which was completed using a force platform on a rigid surface in the same sports centre. Two trials were completed for each test, and the best trial was used for analysis.

30-m sprint test. Players performed two 30-m maximum sprints (CV=0.9%) with at least 5-min rest between attempts. They started each trial from a staggered stance straight position, 0.3-m behind the starting line and were encouraged to perform each sprint as fast as possible. Sprint time was measured using timing gates from Microgate's WITTY System (Microgate, Bolzano, Italy), placed on the starting line and each 10-m interval up to 30-m and 1-m above ground level[38]. Further, a radar gun (Stalker ATS II; Applied Concepts, Richardson, TX, USA), positioned 5-m behind the starting line at a height 1-m, was used to measure instantaneous sprint velocity (recording frequency 47 Hz). The best sprint time was taken for analysis.

****Table 2 near here****

Sprint performance and mechanical outputs were computed using a recently established valid and reliable inverse dynamic field method based on spatiotemporal data[39]. Specifically, raw velocity-time data, obtained from the radar device, were fitted by an exponential function and derived to compute the net horizontal GRF. Individual linear force-velocity relationships were then extrapolated to calculate F_0 (CV=1.7%, V_0 (CV=1.2%)[39] and P_{max} (CV=2.6%). The mechanical effectiveness of force application was computed as RF_{max} and by D_{RF} (CV=1.6%)[40]. Concretely, a higher RF_{max} means that the player can direct the more important part of the total force output forward at the beginning of the sprint. However, a more negative D_{RF} means that this ratio of forces has a greater decrement as the running velocity increase[40]. P_{max} and RF_{max} were calculated using the following equations by Samozino et al[39]:

$$P_{max} = \frac{F_0 \cdot V_0}{4} \quad \text{[Equation 1]}$$

$$RF = \frac{F_H}{\sqrt{F_H{}^2 + F_V{}^2}} \cdot 100 \quad \text{[Equation 2]}$$

P_{max} is the maximum power output, F_0 is the theoretical maximum horizontal force, V_0 is the theoretical maximum velocity, RF is the ratio of forces, F_H is the horizontal force and F_V is the vertical force for each step.

We applied this methodology because we wanted to compare these results with previous studies that used this approach. However, we assume that power is a scalar quantity, this means that power has no direction, only magnitude. Because movement occurs in a three-dimensional Euclidean space, mechanical work is collectively the result of three dimension[41].

****Table 3 near here****

COD speed test. Zigzag COD test was performed according to standard procedures described elsewhere[16]. This test consists of four 5-m sections (20-m of linear sprint) marked with cones set at 100° angles with timing gates placed at the starting and finishing line Microgate's WITTY System (Microgate, Bolzano, Italy), requiring the players to decelerate and accelerate as fast as possible around each cone. Two submaximal and two maximal attempts (CV=2.3%) were performed with a 5-min rest interval between trials. Players started from a standing position with the leading foot placed 0.3-m behind the first pair of timing gates and instructed to complete the test as fast as possible, until crossing the second pair of timing gates, placed 20-m from the starting line. The best time trial was selected for analysis. Then, to evaluate the efficacy of each player's ability to utilize their linear speed during a specific COD task[42], COD_{Speed} and $COD_{Deficit}$ were calculated as follows:

$$COD_{Speed} = \frac{20}{COD_{Time}} \quad \text{[Equation 3]} \qquad COD_{\text{Deficit}} = V_{Sprint} - COD_{Speed} \quad \text{[Equation 4]}$$

The V_{Sprint} used to calculate $COD_{Deficit}$ is the average sprint velocity (0-20 m) obtained from the unloaded sprint test.

****Table 4 near here****

SLJ test. The SLJ was performed according to a protocol previously described[43]. Players performed two practice trials and then two test trials (CV=3.2%), separated by a 90-s rest. The $SLJ_{Distance}$ was measured to the nearest 0.01 m. The best trial was used for analysis.

CMJ test. The CMJ was performed based on a protocol described previously[43] Players performed two submaximal trials and two maximum trials (CV=3.8%), with a 90-s rest between trials. The depth of the countermovement was self-selected and subjects were asked to try and land close to the point of take-off. CMJs were quantified using a Kistler 9286BA portable force platform (Kistler Group, Winterthur, Switzerland). Specifically, CMJ_{Height} and CMJ_{Pmax} were calculated using the software ForceDeck (Vald Performance, Newstead, QLD, Australia). The attempt with the highest CMJ_{Height} was considered for analysis.

****Table 5 near here****

Statistical Analysis

Descriptive statistics were calculated using SPSS 21.0 (IBM SPSS Inc., Chicago, IL, USA). Data are presented as mean and standard deviation (SD). All data were log-transformed for intra-group pre-post differences analysis to reduce bias arising from non-uniformity errors of the data and then analyzed for practical significance using magnitude-based inferences (MBI)[44]. The effect size (ES; 90% confidence interval) in all dependent variables was calculated using the SD. Between-group comparison was performed using an ANCOVA test in SPSS 21.0, using the pre-test values as covariates in order to remove the possible initial bias, caused by the baseline level of each group in the different assessed variables. Between-group ESs were determined by converting the partial eta-squared from the ANCOVA output to Cohen's *d*. Then a customized spreadsheet[45] was used to convert the ANCOVA p-values and the effect statistic to MBI. Threshold values for Cohen's ES statistics were as follows: >0.2 small, >0.6 moderate, >1.2 large, >2.0 very large and >4.0 nearly perfect[44].

The chance that any difference was better/greater (i.e., greater than the smallest worthwhile change), [0.2 multiplied by the between-subject SD, based on Cohen's *d* ES], similar or worse/smaller than the other group, was subsequently calculated[46]. Quantitative chances of an effect being better or poorer were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and >99%, almost certainly. If the chance of having better and poorer was >5%, the true difference was considered unclear[46]. If the chance was >75%, data were considered substantially different.

RESULTS

Tables 2 and 3 show the within-group pre-post differences and inferences on spatiotemporal and kinetic variables of sprint, respectively. Similarly, Tables 4 and 5 show the within-group pre-post differences and inferences on COD and horizontal and vertical jump variables, respectively. Within-group outcomes showed that all resisted training modalities experienced improvements in sprint (*small to moderate*) (Table 2) and COD (*small to large*) performance (Table 3). Moreover, all groups, except URS, enhanced the horizontal jump performance. However, only VRS improved on vertical jump (Table 4). Likewise, Figure 1, 2 and 3 show the between-group comparison on sprint, COD and horizontal and vertical jump variables, respectively. Between-group comparison outcomes revealed that only VRS improved the sprint time compared to HRS (*moderate*) (Figure 1) and COD performance compared to all groups (*moderate to large*) (Figure 2). Additionally, VRS enhanced the countermovement jump (CMJ) performance (*small to large*) compared to the other groups (Figure 3).

DISCUSSION

The present study investigated the effects of 8-week of different RST modalities, on horizontal and vertical jump, sprint and COD performance, during the competitive season of youth soccer players. To our knowledge, this is the first study that compares the effects of a RST program using different types of equipment to provide horizontal and vertical resistance in youth soccer players. The results indicate that our hypothesis was almost completely fulfilled because all training groups experienced improvements in sprint and COD performance, but not in the horizontal and vertical jump. Moreover, VRS obtained greater improvements in vertical jump performance compared to the other groups. However, there were no substantial between-group differences in horizontal jump. In contrast, our second hypothesis, which stated that RST with an added horizontally or vertically-oriented overload will achieve the greatest improvements in horizontal and vertical-oriented exercises, respectively, was rejected.

Regarding the sprint performance, all training groups experienced small to moderate improvements in $T_{0\text{-}10m}$, $T_{10\text{-}20m}$, $T_{20\text{-}30m}$ and $T_{0\text{-}30m}$. Similarly, small improvements in V_{max} and V_0 were observed. These results are in agreement with previous studies that analysed the effect of RST using sleds on sprint performance[15-17,47-53]. Furthermore, small to moderate improvements in F_0 and P_{max} were observed for all intervention groups. The effectiveness of force application, as determined by RF_{max} and D_{RF}, showed small to moderate increases in RF_{max} for all training groups. These findings could be explained by the high specificity of the RST program, independent of resistance modality; since sprinting is the best stimulus to improve sprint[7]. Overall, between-group comparisons (Figure 2) showed unclear outcomes, except in $T_{0\text{-}10m}$ and $T_{0\text{-}30m}$, where VRS obtained moderate greater improvements compared to HRS. Similarly, moderate greater increments in P_{max} were found in favour of URS, CRS and VRS compared to HRS. These findings are in contrast with the idea which explains the importance of horizontal propulsive forces, especially in the acceleration phase of sprint[31]. However, it must be acknowledged that the GRF are slightly different between a sprinting starts from blocks and a more 2-point staggered stance straight position. Moreover, although VRS provides an athlete a more vertical overload stimulus, sprinting is a horizontal-oriented task and thus, the player also has to propel this overload forward with the rest of his body. Concretely, the orientation of GRF changes to a more vertical orientation from the acceleration to maximum speed phase (or as running velocity increase) on sprinting, being the impulse and resultant GRF diagonal when starts from blocks[29-31] and almost vertical when starts in motion[32]. Thus, in soccer where most of sprints start with an initial velocity[32], VRS might offer a more specific stimulus which could explain current findings. Also, VRS provides a greater overload stimulus than the same magnitude of load in the horizontal direction, due to the added effect of gravity. In fact, there was a greater increase in P_{max} with a moderate effect in favour of VRS compared to HRS, probably caused by this higher stimulus. Moreover, it is thought that greater muscle power is necessary for maximum sprint running[54]. Therefore, it is possible that VRS players are able to develop a higher amount of GRF and consequently, propel their body forward faster.

****Figure 1 near here****

Both COD_{Time} and COD_{Speed} likely to almost certainly improved (small to large ES) for all training groups. These results are in agreement with previous findings of RST with sled on COD performance[16,17], and a recent study that reported improvement on COD ability after 6 weeks of RST with COD using weighted vest[18]. The efficacy of each player's ability to utilize their linear speed during a specific COD task, evaluated by $COD_{Deficit}$, showed likely to almost certainly improved, with small to large ES for all groups. These outcomes could be explained by the improvement in COD technique experimented by players and the enhancement on sprinting ability because, as it is well-known, COD ability is partially influenced by the acceleration ability[3]. Between-groups comparison (Figure 3) revealed moderate to large improvements in COD_{Time} and COD_{Speed} in favour of VRS. These findings are in agreement with Rodríguez-Osorio et al.[18] who also showed improvements after 6 weeks of RST with COD with a weighted vest. Moreover, CRS shows greater improvements in COD_{Time} and COD_{Speed} compared to URS. In addition, VRS showed moderate to large lower $COD_{Deficit}$ compared to HRS and URS. These greatest improvements on COD performance observed in the VRS training group, may result from a higher eccentric demand on the extensor muscles during the braking phase due to the vertical-oriented resistance. In addition, greater efficacy in COD tasks has been related to a lower centre of body mass in the moment of turning[4]. Likewise, sprinting using a weighted vest will impose a greater demand during braking after the sprint than with horizontal loading, which might influence eccentric neuromuscular function with a very positive transference to COD ability. However, braking technique or distance was not controlled for in this study.

****Figure 2 near here****

Concerning jump ability, all training groups, except URS, had small to moderate improvements in $SLJ_{Distance}$. However, between-group comparison (Figure 1) only revealed small to large greater improvements in favour of CRS compared to URS in $SLJ_{Distance}$, These results could be explained by the additional mechanical overload experienced by HRS, VRS and CRS groups. Regarding CMJ since all training groups, except HRS, experienced small to moderate improvements in CMJ_{Pmax}. However, only VRS showed small improvements in CMJ_{Height}. Between-group comparison (Figure 1) revealed moderate greater increments in favour of CRS contrasted to VRS and HRS in CMJ_{Pmax}. However, only VRS showed greater improvements in CMJ_{Height} in comparison with HRS (small), CRS (large) and URS (large), which might be caused by the specific vertical overload of the VRS training group, since vertical GRF is a key kinetic component for vertical explosive actions[55]. Also, it is possible that these findings are a consequence of an increase in leg spring stiffness which could indicate a greater SSC behaviour[25] and influence jump height. However, this is only a speculation, because the recorded parameters do not provide the bases for a more specific interpretation of the obtained results.

****Figure 3 near here****

Briefly, the results of this study indicate that the combination of RST with or without COD, independently of the direction of loading, is a good option for improving sprint and COD performance in youth soccer players. However, VRS may be the better training stimulus based on the observed improvements in sprint and COD performance with the additional positive effect on jumping performance.

The main limitations of the present study are: (1) the calculation method used to compute the kinetic variables in sprinting only considers the horizontal components of force and power, and (2) the high experimental drop-out during the intervention period that reduced the sample of each group. Therefore, future studies are needed in order to obtain more evidence about the adaptations provoked by the training methods described in the current study, because there is no previous research that includes alternative equipment to a sled, neither one that compares the effect of different RST modalities with vertical and horizontal load. Moreover, the training dose required to enhance such performances using these training modalities should be established.

PERSPECTIVES

This study provides important information about the effects of different RST modalities horizontally and vertically-oriented on jump ability, sprint performance and COD skills in youth soccer players. Current findings may assist coaches and trainers in the selection of RST training intervention to target sprint and COD performance. Based on our results, VRS using loads ranged between 10-20% BM is the best option for improving linear sprinting and COD performance with an additional positive effect on jumping performance in youth soccer players. Moreover, VRS is the best option for improving $COD_{Deficit}$. Therefore, although all RST modalities have been shown as a good option for improving performance in soccer, VRS is the method that showed greater improvements in sprint performance, COD skills and jump ability. Nevertheless, HRS and CRS may be good options for improving linear sprinting and COD ability.

CONCLUSIONS

Based on the presented results, all RST modalities improved sprinting and COD performance, independently of the orientation of the resistance applied. VRS promoted the greatest improvements on sprint and COD ability and had a positive additional effect on vertical jump ability and the reduction of $COD_{Deficit}$.

REFERENCES

1. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. *J Sport Sci.* 2012;30(7):625-631.
2. Bloomfield J, Polman R, O'Donoghue P. Deceleration and turning movements performed during FA Premier League soccer matches. In: Reilly T, Korkusuz F, eds. *Science and football VI: the Proceedings of the Sixth World Congress on Science and Football.* London: Routledge; 2009:174-181.
3. Brughelli M, Cronin J, Levin G, Chaouachi A. Understanding change of direction ability in sport. *Sports Med.* 2008;38(12):1045-1063.
4. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci.* 2013;13(6):646-652.
5. Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: an update. *Sports Med.* 2005;35(6):501-536.
6. MacDougall D, Sale D. Continuous vs interval training: a review for the athlete and the coach. *Can J Appl Sports Sci.* 1981;6(2):93-97.
7. Alcaraz PE, Carlos-Vivas J, Oponjuru BO, Martínez-Rodríguez A. The effectiveness of resisted sled training (RST) for sprint performance: A systematic review and meta-analysis. *Sports Med.* 2018.
8. Cissik JM. Means and Methods of Speed Training, Part I. *Strength Cond J.* 2004;26(4):24-29.

9. Faccioni A. Assisted and resisted methods for speed development: Part 1. *Mod Athl Coach.* 1994;32(2):3-6.

10. Faccioni A. Assisted and resisted methods for speed development: Part 2. *Mod Athl Coach.* 1994;32(3):8-12.

11. Petrakos G, Morin JB, Egan B. Resisted sled sprint training to improve sprint performance: A systematic review. *Sports Med.* 2016;46(3):381-400.

12. Hrysomallis C. The effectiveness of resisted movement training on sprinting and jumping performance. *J Strength Cond Res.* 2012;26(1):299-306.

13. Alcaraz PE, Elvira JLL, Palao JM. Kinematic, strength, and stiffness adaptations after a short- term sled towing training in athletes. *Scand J Med Sci Sports.* 2014;24(2):279-290.

14. Clark KP, Stearne DJ, Walts CT, Miller AD. The longitudinal effects of resisted sprint training using weighted sleds vs weighted vests. *J Strength Cond Res.* 2010;24(12):3287-3295.

15. de Hoyo M, Gonzalo-Skok O, Sañudo B, et al. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. *J Strength Cond Res.* 2016;30(2):368-377.

16. Gil S, Barroso R, Crivoi do Carmo E, et al. Effects of resisted sprint training on sprinting ability and change of direction speed in professional soccer players. *J Sport Sci.* 2018;36(17):1923-1929.

17. McMorrow BJ, Ditroilo M, Egan B. Effect of heavy resisted sled sprint training during the competitive season on sprint and change-of-direction performance in professional soccer players. *Int J Sports Physiol Perform.* 2019:1-25.

18. Rodríguez-Osorio D, Gonzalo-Skok O, Pareja-Blanco F. Effects of resisted sprint with changes of direction training through several relative loads on physical performance in soccer players. *Int J Sports Physiol Perform.* 2019:1-20.

19. Alcaraz PE, Palao JM, Elvira JL, Linthorne NP. Effects of three types of resisted sprint training devices on the kinematics of sprinting at maximum velocity. *J Strength Cond Res.* 2008;22(3):890-897.

20. Carlos-Vivas J, Marín-Cascales E, Freitas TT, Perez-Gomez J, Alcaraz PE. Force-velocity-power profiling during weighted vest sprinting in soccer. *Int J Sports Physiol Perform.* 2018:1-28.

21. Cronin J, Hansen K, Kawamori N, Mcnair P. Effects of weighted vests and sled towing on sprint kinematics. *Sports Biomech.* 2008;7(2):160-172.

22. De Villarreal ES-S, Requena B, Newton RU. Does plyometric training improve strength performance? A meta-analysis. *J Sci Med Sport.* 2010;13(5):513-522.

23. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. *Sports Med.* 2016;46(10):1419-1449.

24. Kugler F, Janshen L. Body position determines propulsive forces in accelerated running. *J Biomech.* 2010;43(2):343-348.

25. Dello Iacono A, Martone D, Milic M, Padulo J. Vertical-vs. horizontal-oriented drop jump training: chronic effects on explosive performances of elite handball players. *J Strength Cond Res.* 2017;31(4):921-931.

26. Loturco I, Contreras B, Kobal R, et al. Vertically and horizontally directed muscle power exercises: Relationships with top-level sprint performance. *PloS one.* 2018;13(7):e0201475.

27. Arcos AL, Yanci J, Mendiguchia J, Salinero JJ, Brughelli M, Castagna C. Short-term training effects of vertically and horizontally oriented exercises on neuromuscular

performance in professional soccer players. *Int J Sports Physiol Perform.* 2014;9(3):480-488.

28. Morin J-B, Bourdin M, Edouard P, Peyrot N, Samozino P, Lacour J-R. Mechanical determinants of 100-m sprint running performance. *Eur J Appl Physiol.* 2012;112(11):3921-3930.

29. Nagahara R, Mizutani M, Matsuo A, Kanehisa H, Fukunaga T. Step-to-step spatiotemporal variables and ground reaction forces of intra-individual fastest sprinting in a single session. *J Sport Sci.* 2017:1-10.

30. Nagahara R, Mizutani M, Matsuo A, Kanehisa H, Fukunaga T. Association of sprint performance with ground reaction forces during acceleration and maximal speed phases in a single sprint. *J Appl Biomech.* 2017:1-20.

31. Rabita G, Dorel S, Slawinski J, et al. Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. *Scand J Med Sci Sports.* 2015;25(5):583-594.

32. Haugen TA, Tønnessen E, Hisdal J, Seiler S. The role and development of sprinting speed in soccer. *Int J Sports Physiol Perform.* 2014;9(3):432-441.

33. Colyer SL, Nagahara R, Takai Y, Salo AI. How sprinters accelerate beyond the velocity plateau of soccer players: Waveform analysis of ground reaction forces. *Scand J Med Sci Sports.* 2018;28(12):2527-2535.

34. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J Appl Physiol.* 2000;89(5):1991-1999.

35. Morin JB, Edouard P, Samozino P. Technical ability of force application as a determinant factor of sprint performance. *Med Sci Sports Exerc.* 2011;43(9):1680-1688.

36. Loturco I, Pereira LA, Abad CCC, et al. Vertical and horizontal jump tests are strongly associated with competitive performance in 100-m dash events. *J Strength Cond Res.* 2015;29(7):1966-1971.

37. Rodriguez-Marroyo JA, Antoñan C. Validity of the session rating of perceived exertion for monitoring exercise demands in youth soccer players. *Int J Sports Physiol Perform.* 2015;10(3):404-407.

38. Spencer M, Pyne D, Santisteban J, Mujika I. Fitness determinants of repeated-sprint ability in highly trained youth football players. *Int J Sports Physiol Perform.* 2011;6(4):497-508.

39. Samozino P, Rabita G, Dorel S, et al. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scand J Med Sci Sports.* 2016;26(6):648-658.

40. Morin JB, Samozino P. Interpreting power-force-velocity profiles for individualized and specific training. *Int J Sports Physiol Perform.* 2016;11(2):267-272.

41. van der Kruk E, van der Helm F, Veeger H, Schwab A. Power in sports: A literature review on the application, assumptions, and terminology of mechanical power in sport research. *J Biomech.* 2018.

42. Loturco I, Nimphius S, Kobal R, et al. Change-of direction deficit in elite young soccer players. *Ger J Exerc Sport Res.* 2018;48:228-234.

43. Markovic G, Dizdar D, Jukic I, Cardinale M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res.* 2004;18(3):551-555.

44. Hopkins W, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3.

45. Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a P value. *Sportscience.* 2007;11:16-21.

46. Suarez-Arrones L, Arenas C, López G, Requena B, Terrill O, Mendez-Villanueva A. Positional differences in match running performance and physical collisions in men rugby sevens. *Int J Sports Physiol Perform.* 2014;9(2):316-323.

47. Bachero-Mena B, Gonzalez-Badillo JJ. Effects of resisted sprint training on acceleration with three different loads accounting for 5, 12.5, and 20% of body mass. *J Strength Cond Res.* 2014;28(10):2954-2960.

48. Harrison AJ, Bourke G. The effect of resisted sprint training on speed and strength performance in male rugby players. *J Strength Cond Res.* 2009;23(1):275-283.

49. Kawamori N, Newton RU, Hori N, Nosaka K. Effects of weighted sled towing with heavy versus light load on sprint acceleration ability. *J Strength Cond Res.* 2014;28(10):2738-2745.

50. Lockie RG, Murphy AJ, Schultz AB, Knight TJ, de Jonge XAKJ. The effects of different speed training protocols on sprint acceleration kinematics and muscle strength and power in field sport athletes. *J Strength Cond Res.* 2012;26(6):1539-1550.

51. Morin JB, Petrakos G, Jimenez-Reyes P, Brown SR, Samozino P, Cross MR. Very-heavy sled training for improving horizontal force output in soccer players. *Int J Sports Physiol Perform.* 2016;12(6):840-844.

52. Spinks CD, Murphy AJ, Spinks WL, Lockie RG. The effects of resisted sprint training on acceleration performance and kinematics in soccer, rugby union, and Australian football players. *J Strength Cond Res.* 2007;21(1):77-85.

53. West DJ, Cunningham DJ, Bracken RM, et al. Effects of resisted training on acceleration in professional rugby union players. *J Strength Cond Res.* 2013;27(4):1014-1018.

54. Smirniotou A, Katsikas C, Paradisis G, Argeitaki P, Zacharogiannis E, Tziortzis S. Strength-power parameters as predictors of sprinting performance. *J Sports Med Phys Fitness.* 2008;48(4):447-454.

55. Salaj S, Markovic G. Specificity of jumping, sprinting, and quick change-of-direction motor abilities. *J Strength Cond Res.* 2011;25(5):1249-1255.

Table 1. Resisted sprint training program.

Week	Session	Session Type	Specific Work				Sets x (reps x distance/reps recovery)/sets recovery	Load	
			HRS	*VRS*	*CRS*	*URS*		*HRS* *VRS* *CRS*	*URS*
1	1	Sprint	1080 Sprint	WV	WV	None	1 x (2x20 m/60")/3' + 1 x (2x30m/60")	10% BM	BM
	2	COD	1080 Sprint	WV	1080 Sprint	None	1 x (4x10m/60")/3' + 1 x (3x15m/60")	10% BM	BM
2	3	COD	1080 Sprint	WV	WV	None	1 x (3x15m/60")/3' + 1 x (2x20m/60")/3' + 1 x (2x30m/60")	15% BM	BM
	4	Sprint	1080 Sprint	WV	1080 Sprint	None	1 x (5x5m/60")/3' + 1 x (4x10m/60")/3' + 1 x (3x15m/60")	15% BM	BM
3	5	COD	1080 Sprint	WV	WV	None	1 x (3x15m/60")/3' + 1 x (2x20m/60")/3' + 1 x (2x30m/60")	20% BM	BM
	6	Sprint	1080 Sprint	WV	1080 Sprint	None	1 x (5x5m/60")/3' + 1 x (4x10m/60")/3' + 1 x (3x15m/60")	20% BM	BM
4	7	COD	1080 Sprint	WV	WV	None	1 x (2x20m/60")/3' + 1 x (2x30m/60")	15% BM	BM
	8	Sprint	1080 Sprint	WV	1080 Sprint	None	1 x (4x10m/60")/3' + 1 x (3x15m/60")	15% BM	BM
5	9	Sprint	1080 Sprint	WV	WV	None	1 x (3x15m/60")/3' + 1 x (2x20m/60")/3' + 1 x (2x30m/60")	15% BM	BM
	10	COD	1080 Sprint	WV	1080 Sprint	None	1 x (5x5m/60")/3' + 1 x (4x10m/60")/3' + 1 x (3x15m/60")	15% BM	BM
6	11	COD	1080 Sprint	WV	WV	None	1 x (3x15m/60")/3' + 1 x (2x20m/60")/3' + 1 x (2x30m/60")	20% BM	BM
	12	Sprint	1080 Sprint	WV	1080 Sprint	None	1 x (5x5m/60")/3' + 1 x (4x10m/60")/3' + 1 x (3x15m/60")	20% BM	BM
7	13	Sprint	1080 Sprint	WV	WV	None	1 x (3x15m/60")/3' + 1 x (2x20m/60")/3' + 1 x (2x30m/60")	15% BM	BM
	14	COD	1080 Sprint	WV	1080 Sprint	None	1 x (5x5m/60")/3' + 1 x (4x10m/60")/3' + 1 x (3x15m/60")	15% BM	BM
8	15	Sprint	1080 Sprint	WV	WV	None	1 x (2x20m/60")/3' + 1 x (2x30m/60")	10% BM	BM
	16	COD	1080 Sprint	WV	1080 Sprint	None	1 x (4x10m/60")/3' + 1 x (3x15m/60")	10% BM	BM

Abbreviations: VRS = vertical resisted sprint; HRS = horizontal resisted sprint; CRS = combined resisted sprint; URS = unresisted sprint; COD = change-of-direction session; WV = weighted vest; BM = body mass.

Table 2. Within-group pre-post differences and inferences on spatiotemporal variables of sprint.

	Training Group	Pre-Test Mean ± SD	Post-Test Mean ± SD	Standardized differences (90% CI)	Chances (%)	Inferences	*P*
$T_{0\text{-}10m}$	HRS	2.11 ± 0.03	2.08 ± 0.02	-0.91 ± 0.31	0/0/100	Moderate**** (positive)	<0.001
	VRS	2.10 ± 0.07	2.07 ± 0.06	-0.43 ± 0.17	0/8/92	Small** (positive)	0.001
	CRS	2.11 ± 0.03	2.08 ± 0.03	-1.00 ± 0.32	0/0/100	Moderate**** (positive)	<0.001
	URS	2.10 ± 0.07	2.06 ± 0.07	-0.51 ± 0.15	0/0/100	Small**** (positive)	<0.001
$T_{10\text{-}20m}$	HRS	1.29 ± 0.02	1.27 ± 0.02	-0.74 ± 0.34	0/1/99	Moderate*** (positive)	0.002
	VRS	1.27 ± 0.05	1.25 ± 0.05	-0.33 ± 0.12	0/3/97	Small*** (positive)	<0.001
	CRS	1.28 ± 0.03	1.26 ± 0.03	-0.64 ± 0.32	0/1/99	Moderate*** (positive)	0.004
	URS	1.27 ± 0.06	1.25 ± 0.05	-0.33 ± 0.15	0/8/92	Small** (positive)	0.003
$T_{20\text{-}30m}$	HRS	1.21 ± 0.03	1.20 ± 0.03	-0.45 ± 0.36	0/11/88	Small** (positive)	0.043
	VRS	1.19 ± 0.05	1.17 ± 0.05	-0.34 ± 0.11	0/3/97	Small*** (positive)	<0.002
	CRS	1.20 ± 0.03	1.19 ± 0.03	-0.50 ± 0.35	0/8/92	Small** (positive)	0.028
	URS	1.19 ± 0.06	1.17 ± 0.06	-0.31 ± 0.14	0/10/90	Small** (positive)	0.003
$T_{0\text{-}30m}$	HRS	4.61 ± 0.07	4.55 ± 0.07	-0.76 ± 0.32	0/0/100	Moderate**** (positive)	0.001
	VRS	4.55 ± 0.17	4.49 ± 0.16	-0.37 ± 0.11	0/1/99	Small*** (positive)	<0.001
	CRS	4.59 ± 0.09	4.52 ± 0.08	-0.73 ± 0.32	0/1/99	Moderate*** (positive)	0.002
	URS	4.56 ± 0.19	4.49 ± 0.17	-0.39 ± 0.14	0/2/98	Small*** (positive)	<0.001
V_{max}	HRS	8.36 ± 0.21	8.47 ± 0.18	0.48 ± 0.33	92/8/0	Small*** (positive)	0.025
	VRS	8.56 ± 0.41	8.68 ± 0.39	0.26 ± 0.12	82/18/0	Small*** (positive)	0.003
	CRS	8.43 ± 0.23	8.56 ± 0.22	0.52 ± 0.35	94/6/0	Small*** (positive)	0.022
	URS	8.51 ± 0.44	8.65 ± 0.41	0.28 ± 0.14	84/16/0	Small*** (positive)	0.004
V_0	HRS	8.78 ± 0.25	8.90 ± 0.23	0.48 ± 0.34	92/8/0	Small*** (positive)	0.027
	VRS	9.03 ± 0.49	9.17 ± 0.49	0.26 ± 0.12	77/23/0	Small*** (positive)	0.006
	CRS	8.86 ± 0.28	9.01 ± 0.27	0.49 ± 0.36	92/8/0	Small*** (positive)	0.032
	URS	8.96 ± 0.53	9.13 ± 0.50	0.30 ± 0.13	91/9/0	Small*** (positive)	0.002

Abbreviations: $T_{0\text{-}10m}$ = time from starting point to 10m in s; $T_{10\text{-}20m}$ = time from 10m to 20m in s; $T_{20\text{-}30m}$ = time from 20m to 30m in s; $T_{0\text{-}30m}$ = full sprint time in s; V_{max} = maximum velocity in $m \cdot s^{-1}$; V_0 = theoretical maximum velocity in $m \cdot s^{-1}$; HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint; SD = standard deviation; CI = confidence interval; Chances = percentage chance of having greater/similar/lower values as a percentage; *P* = p-value. Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), likely (75–95%), very likely (95–99%) and almost certainly (>99%). Positive, trivial and negative indicators refer to the effect on performance of the change between post- and pre-values for each specific variable.

Table 3. Within-group pre-post differences and inferences on kinetic variables of sprint.

	Training Group	**Pre-Test** Mean ± SD	**Post-Test** Mean ± SD	**Standardized differences** (90% CI)	**Chances (%)**	**Inferences**	***P***
F_0	HRS	7.79 ± 0.18	7.95 ± 0.20	0.84 ± 0.44	99/1/0	Moderate*** (positive)	0.006
	VRS	7.69 ± 0.40	7.95 ± 0.39	0.57 ± 0.29	98/2/0	Small*** (positive)	0.005
	CRS	7.66 ± 0.21	7.94 ± 0.18	1.20 ± 0.35	100/0/0	Moderate**** (positive)	<0.001
	URS	7.78 ± 0.36	7.98 ± 0.34	0.51 ± 0.18	100/0/0	Small**** (positive)	<0.001
P_{max}	HRS	17.1 ± 0.74	17.7 ± 0.67	0.72 ± 0.38	98/2/0	Moderate*** (positive)	0.005
	VRS	17.4 ± 1.71	18.2 ± 1.58	0.45 ± 0.15	99/1/0	Small*** (positive)	<0.001
	CRS	17.0 ± 0.85	17.9 ± 0.75	0.97 ± 0.31	100/0/0	Moderate**** (positive)	<0.001
	URS	17.4 ± 1.77	18.2 ± 1.66	0.41 ± 0.14	99/1/0	Small*** (positive)	<0.001
RF_{max}	HRS	44.9 ± 0.86	45.6 ± 0.65	0.76 ± 0.41	98/2/0	Moderate*** (positive)	0.006
	VRS	45.2 ± 1.66	46.0 ± 1.67	0.45 ± 0.18	98/2/0	Small*** (positive)	0.001
	CRS	44.9 ± 0.90	45.8 ± 0.84	0.94 ± 0.42	100/0/0	Moderate**** (positive)	0.002
	URS	45.3 ± 1.92	46.3 ± 1.77	0.44 ± 0.17	99/1/0	Small*** (positive)	<0.001
D_{RF}	HRS	-8.29 ± 0.25	-8.30 ± 0.30	-0.02 ± 0.43	21/53/26	Unclear	0.94
	VRS	-7.94 ± 0.35	-8.05 ± 0.44	-0.27 ± 0.41	3/35/62	Small* (negative)	0.264
	CRS	-8.07 ± 0.27	-8.19 ± 0.28	-0.41 ± 0.45	2/20/82	Small** (negative)	0.134
	URS	-8.10 ± 0.29	-8.11 ± 0.32	-0.04 ± 0.24	5/81/13	Unclear	0.781

Abbreviations: F_0 = theoretical maximum horizontal force in $N \cdot kg^{-1}$; P_{max} = maximum horizontal power output in $W \cdot kg^{-1}$; RF_{max} = maximum ratio of forces, as a percentage; D_{RF} = decrease in ratio of forces, as a percentage; HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint; SD = standard deviation; CI = confidence interval; Chances = percentage chance of having greater/similar/lower values as a percentage; *P* = p-value. Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), likely (75–95%), very likely (95–99%) and almost certainly (>99%). Positive, trivial and negative indicators refer to the effect on performance of the change between post- and pre-values for each specific variable.

Table 4. Within-group pre-post differences and inferences on change-of-direction ability variables.

	Training Group	Pre-Test Mean ± SD	Post-Test Mean ± SD	Standardized differences (90% CI)	Chances (%)	Inferences	*P*
COD_{Time}	HRS	4.97 ± 0.20	4.73 ± 0.25	-1.22 ± 0.47	0/0/100	Large**** (positive)	<0.001
	VRS	4.90 ± 0.25	4.52 ± 0.21	-1.47 ± 0.37	0/0/100	Large**** (positive)	<0.001
	CRS	4.98 ± 0.23	4.65 ± 0.18	-1.39 ± 0.41	0/0/100	Large**** (positive)	<0.001
	URS	4.90 ± 0.28	4.74 ± 0.25	-0.52 ± 0.39	0/0/100	Small** (positive)	0.035
COD_{Speed}	HRS	4.03 ± 0.16	4.24 ± 0.21	1.22 ± 0.47	100/0/0	Large**** (positive)	<0.001
	VRS	4.09 ± 0.21	4.44 ± 0.21	1.47 ± 0.37	100/0/0	Large**** (positive)	<0.001
	CRS	4.02 ± 0.18	4.30 ± 0.16	1.39 ± 0.41	100/0/0	Large**** (positive)	<0.001
	URS	4.10 ± 0.23	4.23 ± 0.23	0.52 ± 0.39	100/0/0	Small** (positive)	0.035
$COD_{Deficit}$	HRS	1.86 ± 0.14	1.65 ± 0.24	-1.67 ± 0.67	0/0/100	Large**** (positive)	<0.001
	VRS	1.86 ± 0.31	1.51 ± 0.26	-1.13 ± 0.25	0/0/100	Moderate**** (positive)	<0.001
	CRS	1.88 ± 0.19	1.60 ± 0.17	-1.44 ± 0.39	0/0/100	Large**** (positive)	<0.001
	URS	1.85 ± 0.24	1.72 ± 0.23	-0.53 ± 0.40	0/0/100	Small** (positive)	0.037

Abbreviations: COD_{Time} = change-of-direction test time in s; COD_{Speed} = change-of-direction test average speed in $m \cdot s^{-1}$; $COD_{Deficit}$ = change-of-direction speed deficit in $m \cdot s^{-1}$; HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint; SD = standard deviation; CI = confidence interval; Chances = percentage chance of having greater/similar/lower values as a percentage; *P* = p-value. Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), **likely (75–95%), ***very likely (95–99%) and ****almost certainly (>99%). Positive, trivial and negative indicators refer to the effect on performance of the change between post- and pre-values for each specific variable.

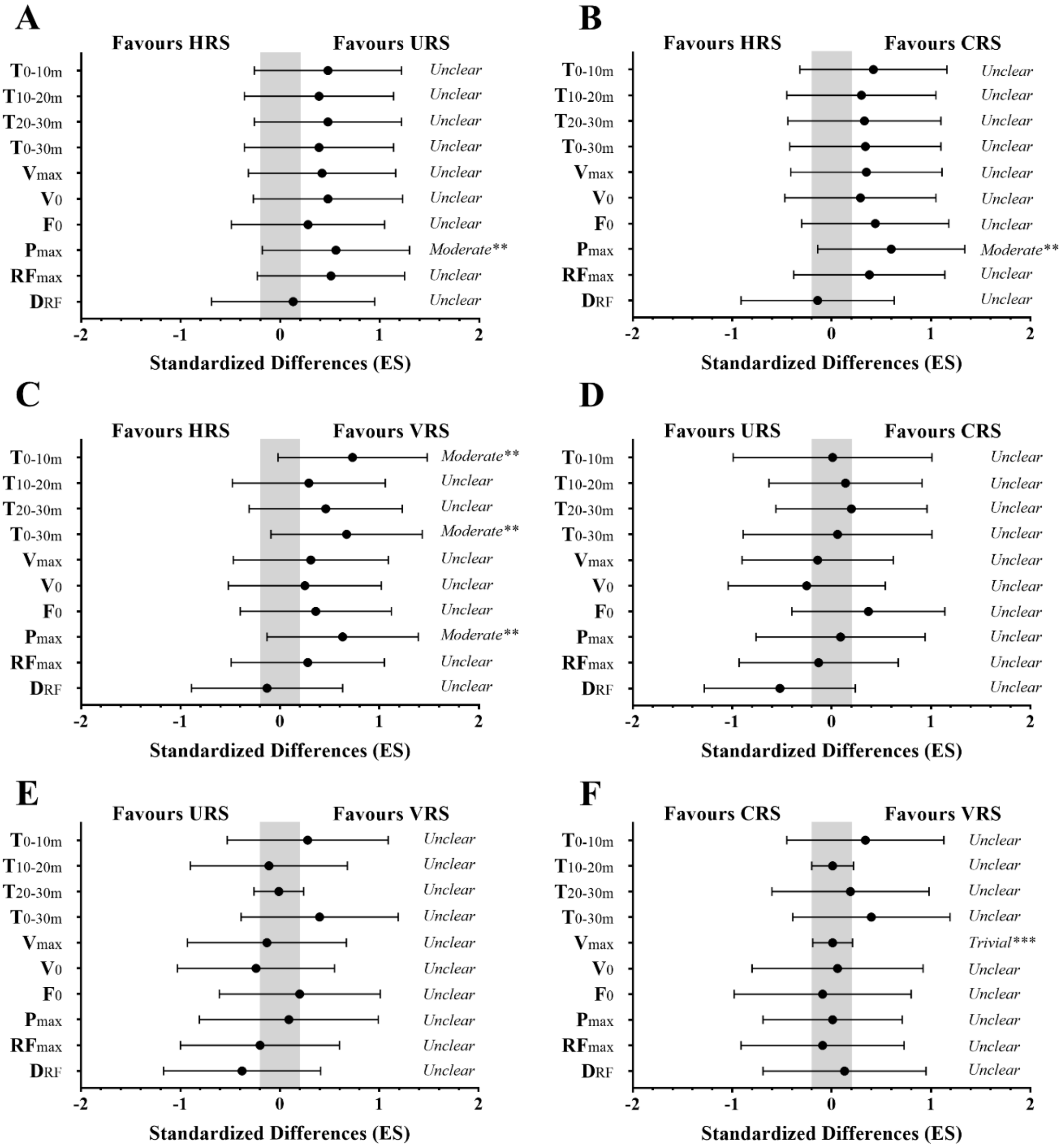
Table 5. Within-group pre-post differences and inferences on horizontal and vertical jump variables.

	Training Group	Pre-Test Mean ± SD	Post-Test Mean ± SD	Standardized differences (90% CI)	Chances (%)	Inferences	*P*
$SLJ_{Distance}$	HRS	2.12 ± 0.13	2.22 ± 0.13	0.63 ± 0.47	93/6/0	Moderate** (positive)	0.035
	VRS	2.26 ± 0.17	2.31 ± 0.20	0.29 ± 0.24	74/26/0	Small* (positive)	0.060
	CRS	2.14 ± 0.21	2.23 ± 0.18	0.39 ± 0.24	91/9/0	Small** (positive)	0.015
	URS	2.17 ± 0.14	2.20 ± 0.20	0.14 ± 0.41	40/52/8	Unclear	0.542
CMJ_{Pmax}	HRS	48.9 ± 4.15	50.5 ± 4.69	0.36 ± 0.48	68/26/6	Unclear	0.298
	VRS	51.5 ± 7.00	53.8 ± 6.03	0.30 ± 0.15	87/13/0	Small* (positive)	0.005
	CRS	48.4 ± 4.62	52.7 ± 6.69	0.81 ± 0.37	99/1/0	Moderate*** (positive)	0.002
	URS	50.2 ± 7.73	53.1 ± 6.05	0.38 ± 0.26	88/12/0	Small** (positive)	0.023
CMJ_{Height}	HRS	35.2 ± 3.83	35.4 ± 4.71	0.02 ± 0.40	22/61/17	Unclear	0.922
	VRS	37.4 ± 8.42	40.0 ± 7.59	0.31 ± 0.09	97/3/0	Small*** (positive)	<0.001
	CRS	35.4 ± 4.30	35.8 ± 4.12	0.11 ± 0.28	28/68/4	Trivial* (trivial)	0.499
	URS	36.6 ± 4.39	35.8 ± 5.11	-0.20 ± 0.38	4/47/49	Trivial* (negative)	0.371

Abbreviations: $SLJ_{Distance}$ = standing long jump distance in m; CMJ_{Pmax} = maximum power production reached in countermovement jump in $W \cdot kg^{-1}$; CMJ_{Height} = maximum jump height reached in countermovement jump in cm; HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint; SD = standard deviation; CI = confidence interval; Chances = percentage chance of having greater/similar/lower values as a percentage; *P* = p-value. Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), **likely (75–95%), ***very likely (95–99%) and ****almost certainly (>99%). Positive, trivial and negative indicators refer to the effect on performance of the change between post- and pre-values for each specific variable.

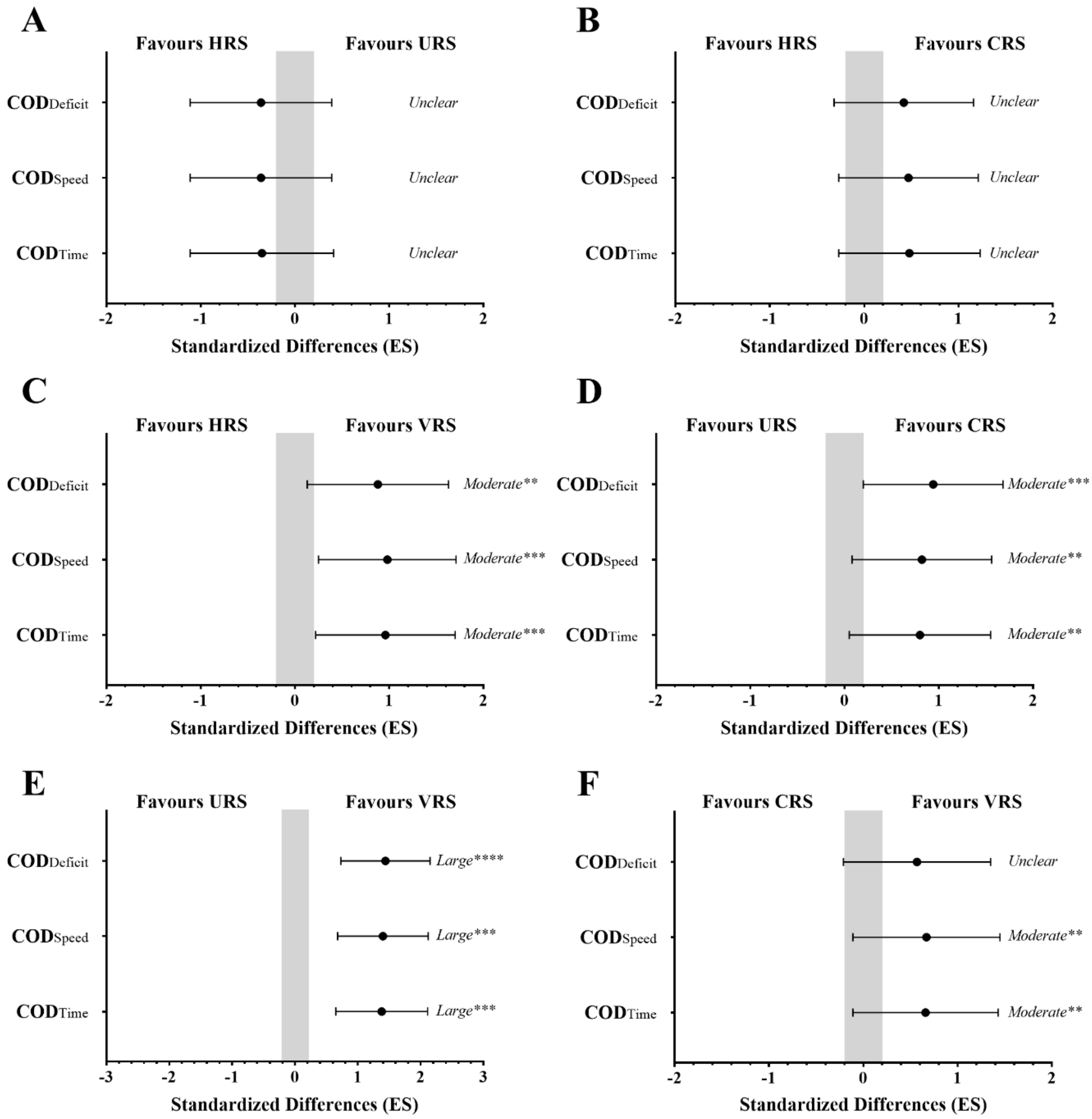
FIGURE CAPTIONS

Figure 1. Between-group comparison of sprint performance.



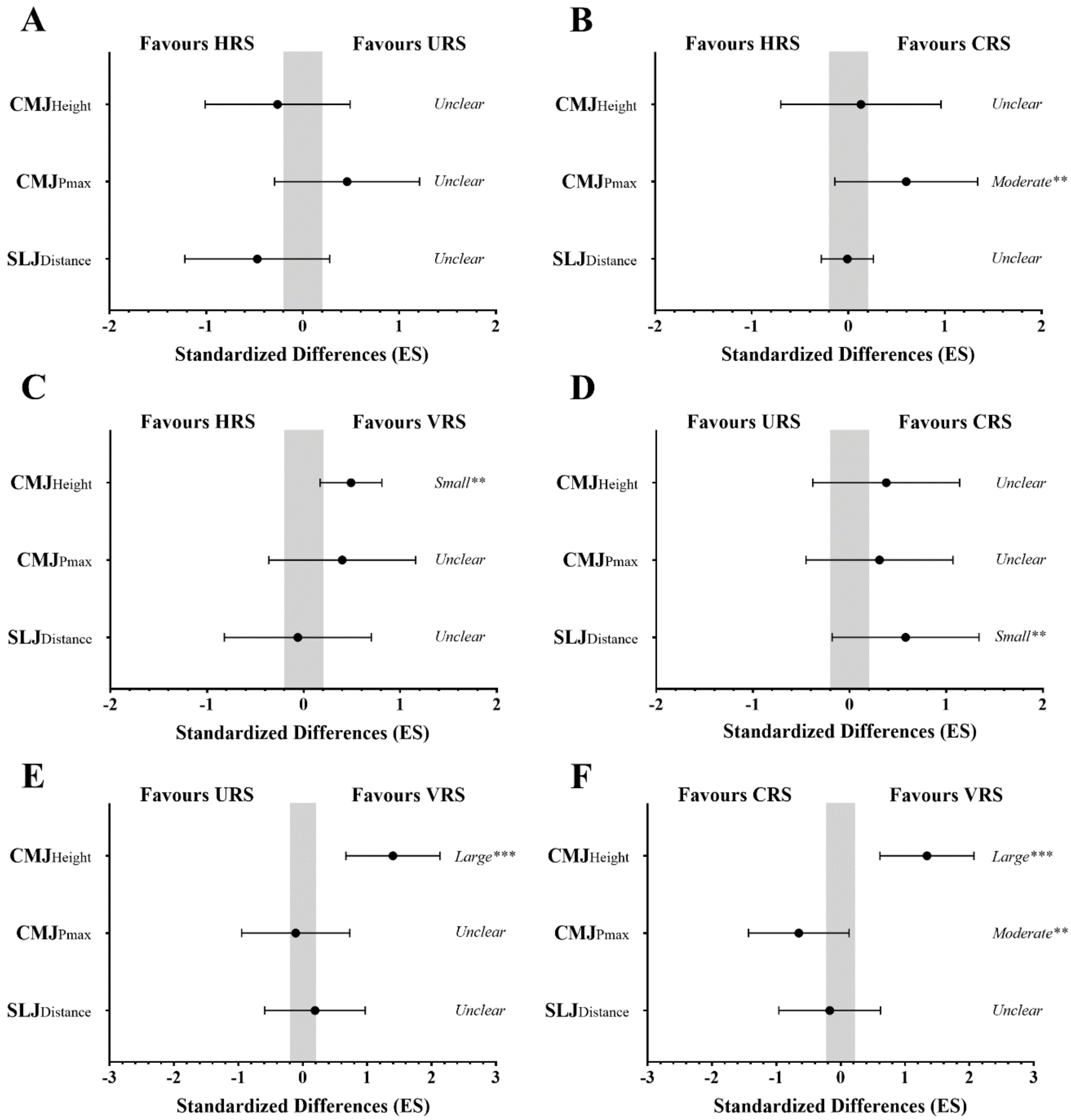
Bars indicate uncertainty in the true mean changes with 90% confidence intervals. Abbreviations: $T_{0\text{-}10m}$ = time from starting point to 10m (s); $T_{10\text{-}20m}$ = time from 10m to 20m (s); $T_{20\text{-}30m}$ = time from 20m to 30m (s); $T_{0\text{-}30m}$ = full sprint time (s); V_{max} = maximum velocity ($m \cdot s^{-1}$); V_0 = theoretical maximum velocity ($m \cdot s^{-1}$); F_0 = theoretical maximum horizontal force in ($N \cdot kg^{-1}$); P_{max} = maximum horizontal power output in ($W \cdot kg^{-1}$); RF_{max} = maximum ratio of forces (%); D_{RF} = decrease in ratio of forces (%); HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint. Effect size (ES). Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), likely (75–95%), very likely (95–99%) and almost certainly (>99%).

Figure 2. Between-group comparison of change-of-direction performance.



Bars indicate uncertainty in the true mean changes with 90% confidence intervals. Abbreviations: COD_{Time} = change-of-direction test time (s); COD_{Speed} = change-of-direction test average speed ($m{\cdot}s^{-1}$); $COD_{Deficit}$ = change-of-direction speed deficit in ($m{\cdot}s^{-1}$); HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint. Effect size (ES). Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), **likely (75–95%), ***very likely (95–99%) and ****almost certainly (>99%).

Figure 3. Between-group comparison of horizontal and vertical jump performance.



Bars indicate uncertainty in the true mean changes with 90% confidence intervals. Abbreviations: $SLJ_{Distance}$ = standing long jump distance (m); CMJ_{Pmax} = maximum power production reached in countermovement jump ($W \cdot kg^{-1}$); CMJ_{Height} = maximum jump height reached in countermovement jump (cm); HRS = horizontal resisted sprint; URS = unresisted sprint; CRS = combined resisted sprint; VRS = vertical resisted sprint. Effect size (ES). Inferences are small (>0.2), moderate (>0.6) moderate, large (>1.2), very large (>2.0) and nearly perfect (>4.0). Qualitative assessment: *possibly (25–75%), **likely (75–95%), ***very likely (95–99%) and ****almost certainly (>99%).