Optimal reactive strength index: Is it an accurate variable to optimize plyometric training effects on measures of physical fitness in young soccer players?

R., Ramirez-Campillo; Álvarez, Cristian; García Pinillos, Felipe; Sánchez, Javier; Javier, Yanci; Castillo, Daniel; Loturco, Irineu; Chaabene, Helmi; Moran, Jason; Izquierdo, Mikel

Published in:
Journal of Strength and Conditioning Research

Publication date:
2018

Citation for published version (APA):
R., R.-C., Álvarez, C., García Pinillos, F., Sánchez, J., Javier, Y., Castillo, D., Loturco, I., Chaabene, H., Moran, J., & Izquierdo, M. (2018). Optimal reactive strength index: Is it an accurate variable to optimize plyometric training effects on measures of physical fitness in young soccer players? *Journal of Strength and Conditioning Research*, *32*(4), 885-893. https://doi.org/10.1519/JSC.0000000000002467

Optimal Reactive Strength Index: Is It An Accurate Variable To Optimize Plyometric Training Effects On Measures Of Physical Fitness In Young Soccer Players?

This is a non-final version of an article published in final form in the Journal of Strength and Conditioning Research. 32(4):885–893, APR 2018. The final published form can be accessed at https://doi.org/10.1519/JSC.0000000000002467

ABSTRACT

This study aimed to compare the effects of drop-jump training using a fixed drop-box height (i.e., 30-cm [FIXED]) versus an optimal drop-box height (i.e, 10-cm to 40-cm: generating an optimal [OPT] reactive strength index [RSI]) in youth soccer players' physical fitness. Athletes were randomly allocated to a control-group (CG: n=24; age=13.7 years), a fixed drop-box height group (FIXED, n=25; age=13.9 years) or an optimal drop-box height group (OPT, n=24; age=13.1 years). Before and after 7 weeks of training, tests for the assessment of jumping (countermovement jump [CMJ], five multiple bounds [MB]), speed (20-m sprint time), change of direction (Illinois change of direction test [CODT]), strength (RSI and 5 maximal squat repetition test [5RM]), endurance (2.4 km time trial), and kicking ability (maximal kicking distance) were undertaken. Analyses revealed main effects of time for all dependent variables (p<0.001, d=0.24-0.72), except for 20-m sprint time. Analyses also revealed group×time interactions for CMJ (p<0.001, d=0.51), DJ (p<0.001, d=0.30), 20-m sprint time (p<0.001, d=0.25), CODT (p<0.001, d=0.22), and 5RM (p<0.01, d=0.16). Post-hoc analyses revealed increases for the FIXED group (CMJ: 7.4%, d=0.36; DJ: 19.2%, d=0.49; CODA: -3.1%, d=-0.21; 5RM: 10.5%, d=0.32) and the OPT group (CMJ: 16.7%, d=0.76; DJ: 36.1%, d=0.79; CODA: -4.4%, d=-0.34; 5RM: 18.1%, d=0.47). Post-hoc analyses also revealed increases for the OPT group in 20-m sprint time (-3.7%, d=0.27). Therefore, to maximize the effects of plyometric training, an OPT approach is recommended. However, using adequate fixed drop-box heights may provide a rational and practical alternative.

KEY WORDS: football; stretch-shortening cycle; maturity; training optimization; strength; change of direction; jumping.

INTRODUCTION

Previous findings revealed that plyometric jump training (PJT) increases tendon stiffness, which allows a faster and more effective transfer of force from muscle to bone (18). Such an effect may improve the physical fitness of youth athletes (27). Likewise, by being integrated into the regular training schedule of young soccer players, PJT can improve a wide range of physical fitness variables such as jump performance, running speed, COD ability, muscular endurance, and maximal strength (6, 31, 37). In fact, scientific data has indicated that PJT is an effective and safe training method for soccer players (6) that enables youths to cope with the growing physical demands of modern soccer (29).

To adequately implement PJT programs, several factors should be considered such as the nature of jump surface (31), training overload (37), training volume (31), the type of jump drill (7), and jumping intensity. Generally, to increase PJT intensity, athletes execute vertical jumps at progressively increasing heights (i.e., drop jumps) (10). Indeed, greater electromyographic responses have been observed during drop jumps performed from a 60-cm box than from 40-cm (8) or 20-cm boxes (28). However, although power output and reactive strength index (RSI) may augment with initial increases in drop height, if height continues to increase the jump performance may be impaired (22). Moreover, increasing the drop height during drop jumps does not ensure greater electromyographic responses in all targeted muscle groups (3). Thus, the use of “optimal drop heights” based on the highest RSI values have been suggested as a simple and effective way to prescribe plyometric training routines (22).

Many strength and conditioning coaches prescribe plyometric training sessions using fixed box heights (i.e., a 30-cm box), considering, for example, the mean countermovement jump performance of the subjects a good parameter for defining optimal dropping height (22). In fact, previous interventions adopting this method have been shown to be effective for enhancing power-related capacities in youth soccer players (13, 35, 44). However, with current data, we cannot determine which of the above methods is more effective and this can potentially violate the training principle of individualization.

Therefore, the aim of this study was to compare the effects of vertical-oriented jump training using a fixed box height (i.e., 30-cm [FIXED]) or an optimal box height (i.e., generating an optimal RSI [OPT]) on measures of physical fitness of youth soccer players. Based on biomechanical aspects (22) and our previous experience with youth athletes, we hypothesized that both training approaches would be capable of improving youth players' performance, with greater improvements after training in the OPT group.

METHODS

Experimental Approach to the Problem

To compare the effects of vertical-oriented jump training using a fixed box height or an optimal box height on measures of physical fitness of youth soccer players, a single-blind randomized controlled trial was conducted. Athletes were randomly allocated to a control-group, a fixed drop-box height group or an optimal drop-box height group. Before and after 7 weeks of training, tests for the assessment of jumping, sprinting, change of direction, strength, endurance, and kicking ability were undertaken.

Subjects

Seventy-three national-level young male soccer players (age, 10.9 to 15.9 years) were recruited from a professional soccer academy. At recruitment and during the in-season training period (mid part of the in-season), players completed four training sessions plus a competitive match per-week. Players had similar competitive schedules and trained under the same head coach. In a single-blind randomized controlled design, participants were allocated to one of three groups: fixed drop-box height group (FIXED, n=25), optimal drop-box height group (OPT, n=24), and a control group (CG, n=24). Participants' characteristics are presented in Table 1. A similar number of goalkeepers (2; 1; 1), defenders (8; 6; 7), midfielders (7; 9; 7) and forwards (8; 8; 9) were present in the FIXED, OPT, and CG, respectively. The training groups underwent a plyometric training program in substitution for some technical-tactical soccer-drills, whereas the control group followed their regular soccer training. The randomization sequence was generated electronically (https://www.randomizer.org) and concealed until interventions were assigned. The following inclusion criteria were considered: (1) two years of systematic soccer training and competition, (2) free of musculoskeletal injuries during the last six months, (3) no systematic plyometric and strength training experience in the previous five months, (4) attendance to ≥90% of all training sessions during the intervention.

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

The sample size was determined according to changes in plyometric (i.e., vertical jump) performance in a group of trained youth male soccer players submitted to a control group (Δ=0.5 cm; standard deviation=1.1) or to a short-term plyometric training (Δ=2.6 cm; standard deviation=1.6) group (32) comparable with that applied in this study. Eight participants per group would yield a statistical power of 80% (i.e., type II error rate of 0.20) and α=0.05 (i.e., assumed type I error), using an effect size of 0.2.

Participants (and their respective parents or guardians) were informed about the experimental procedures, possible risks and benefits associated with participation in the study. They then signed informed assent and consent forms, respectively, before performing any of the tests and training sessions. The study was carried out in accordance with the ethical standards of international sport medicine institutions (14), including the American College of Sports Medicine’s policies for human experimentation, and was approved by the ethical review board from the responsible institutional department.

Procedures

Participants were accustomed to procedures (six 15 min learning sessions during two weeks) to reduce learning effects. In addition, some of the performance tests were regularly used in the monitoring of training sessions. Before, and immediately after, the intervention period, standardized tests were scheduled. These were ≥72 h after a match or hard physical training session. Tests were completed in the same order, at the same time of day, indoor venue, with the same sports clothes, and by the same investigator, who was blinded to the training group of the participants. All players (and their guardians) were instructed to (1) have a good night's sleep (≥8 h) before each testing day (2) have a meal rich in carbohydrates and (3) be well hydrated before assessment.

The participants were asked to give their maximum effort during testing and verbal encouragement was continually provided. Athletes were evaluated across a three-day period. On the first day, age, stature, body mass, maturity, weekly time in physical education classes, weekly hours of other sport or soccer in other club, years of soccer experience, countermovement jump, five multiple bounds test, and the 20-cm drop jump RSI test were completed. In addition, athletes were assessed for optimal box height for development of optimal reactive strength (see training program section for details). On the second day, the 20-m sprint, Illinois change of direction time test, and the 2.4-km time trial run endurance test were carried out. On the third day, the maximal kicking ability and the 5-RM squat tests were scheduled. The best score from three attempts was recorded for all performance tests, apart from the single 2.4-km time trial run and the 5-RM squat tests. A rest interval of at least two minutes was allowed between each physical performance trial to reduce fatigue effects, and a rest interval of 5-10 minutes was allowed between tests. While waiting, participants performed low-intensity activity (i.e., ball passes) to maintain readiness for the next test. Ten minutes of general (i.e., submaximal running with change of direction) and a specific warm-up (2) (20 vertical and 10 horizontal submaximal jumps) were used before each testing session. In addition, participants performed a test-specific warm-up that comprised two practice attempts for each test, except for the shuttle run endurance test, where players completed the first minute of the test as a warm-up phase. Lastly, a specific warm-up was also completed before the 5RM squat test (see details below).

Anthropometry. Comprised stature on a stadiometer (Bodymeter 206, SECA, Hamburg, Germany, to 0.1 cm) and body mass on an electrical scale (InBody120, model BPM040S12FXX, Biospace, Inc., Seoul, Korea, to 0.1 kg), using standard measurement protocols. Maturity was determined by self-assessment (42). Athletes were asked to self-determine maturity stage using standard diagrams of pubic hair growth and penis/scrotum development. Privacy was maintained from other subjects and investigators by providing booths for completing forms and placing them in sealed, coded envelopes for later analysis.

Jumping performance. Protocols used for the athletic performance tests were according to previous recommendations (31, 33, 36). For the vertical jumps, players executed maximal effort jumps on a mobile contact mat (Ergojump; Globus, Codogne, Italy) with arms akimbo. Take-off and landing were standardized to full knee and ankle extension on the same spot. The participants were instructed to maximize jump height. In addition, for the 20-cm drop jump RSI, players were instructed to minimize ground contact time after dropping down from a 20-cm drop box. The RSI was calculated from jump flight time (ms) divided by contact time (ms). The 5 multiple bounds test was performed using a 15-m fiberglass metric tape laid on a wooden floor. Subjects were instructed to jump positioning (behind the starting line) their feet shoulders wide apart and to perform a fast downward movement (approximately 120° knee angle) followed by a maximal effort horizontal jump, landing with one foot. Then, athletes performed a set of four additional forward jumps with alternative left- and right-leg contacts to cover the longest distance possible. The distance was measured, to the nearest centimeter, using from the starting line to the point where the heels of the subjects make contact with the ground after the last landing (23).

Sprinting performance. The sprint time was assessed to the nearest 0.01 s using timing gates (Brower Timing System, Salt Lake City, UT, USA). Participants had a standing start with the toe of the preferred foot forward and just behind the starting line. Sprint start when athletes voluntarily initiate the test, which triggered timing. The timing gates were positioned at the beginning (0.3 m in front of the starting line) (1) and at 20-m and set ~0.7 m above the floor (i.e., hip level). To increase the accuracy and reliability of measurements (15), two synchronized single-beam timing gates were mounted one over the other. With this double-photocell system, only the simultaneous interruption of both the single-beam photocells generates a signal. This system ensures to capture trunk movement rather than a false trigger from a limb. For the Illinois change of direction speed test, the timing system and procedures were same as for the 20-m sprint, except that players had to run in a straight line with maximal effort with several changes of directions (16).

Endurance performance. For the 2.4-km time trial run test, athletes completed a warm-up of 800-m and four minutes of rest. After that, athletes performed six laps of a 400-m outdoor tartan track, timed to the nearest second using a stopwatch. Athletes were instructed to run for maximal performance. Motivation was considered very high, as this test was conducted as part of the selection process for scholarship opportunities within the soccer club, as regularly programmed by the staff of the team. Athletes had one maximal attempt to complete the test. The wind velocity at all times was between 3 and 9 $km \cdot h^{-1}$, the relative humidity was between 50 and 80%, and the temperature was between 14 and 19° C (local Meteorological Service). The time that athletes took to complete the test was registered in minutes.

Maximal kicking distance. After a standard specific warm-up, players kicked a new size five soccer ball (FIFA certified) for maximal distance on an official soccer field. Two markers were placed on the ground side by side to define the kick line. Participants performed a maximal instep kick with their dominant leg after a run up of two strides. A 75-m metric tape was placed between the kicking line and across the soccer field. An assessor was placed near the region where the ball land after the kick to mark the point of contact and to measure the distance kicked. The distance was measured to the nearest ~0.2 m. All measurements were completed with a wind velocity between 2 and 4 km·h^{-1}, and the relative humidity was between 40 and 70% (local Meteorological Service). Previous studies have reported a high reliability of similar soccer kicking test (19).

Maximal strength. Was assessed using concentric-eccentric 5RM parallel squat action. The assessments were completed using free weights (after athletes had participated in six practice sessions), with the participant assuming an initial erect position with the bar behind the shoulders. Then, the participants lowered the bar until the upper portion of the thighs was parallel with the floor (determined visually by an experienced investigator). Finally, the participant performed a concentric leg extension (as fast as possible) to reach the full extension of 180° against the resistance determined by the weight. This action was repeated five times, with the maximum weight possible. Warm-up consisted of a set of 10 repetitions at loads of 40–60% of the perceived maximum (according to practice sessions). After one minute of rest and mild stretching, participants performed a second set of 3–5 repetitions at loads of 60–80% of the perceived maximum. Thereafter, the athletes had a maximum of five separate attempts to find their 5RM. The last acceptable five consecutive repetitions with highest possible load (kilograms) were determined as 5RM. The rest period between the actions was ~5 minutes. The reliability of lower-body 5RM testing have been previously stablished (11).

Training Program

Before beginning the training period, players were instructed on how to perform all the exercises, with an emphasis on technique of jumps execution. The plyometric training was completed during the mid-portion of player's competition period. The control group did not perform the plyometric training, but performed their usual soccer training (i.e., mainly technical-tactical, small-sided and simulated games, injury prevention). The design of the plyometric intervention was based on the players' previous training records, as well as previous research results (30, 34, 35). Plyometric training was not added to the regular training of soccer players, instead a replacement of some low-intensity technical-tactical soccer drills by plyometric drills was performed within their usual 120 min training, twice per week, during the 7-week intervention period. Plyometric jump training (i.e., 178 minutes) replaced ~5.3% of the total soccer training time (i.e., 3,360 minutes; other than competitive and friendly matches). Each plyometric training session lasted a mean of ~13 minutes (range: 10-17 minutes).

Each plyometric session included maximal-effort vertical-oriented drop jumps, performed with involvement of stretch-shortening cycle muscle activity, with arms akimbo. The FIXED group performed maximal-effort drop jumps from a box height of 30-cm. This height was chosen as it was the mean countermovement jump performance of the group before the intervention, an height deemed as effective for drop jumps (22). Therefore, the box height was not individualized for this group. Athletes from the OPT group performed maximal-effort vertical-oriented drop jumps from an individualized box height to allow the achievement of optimal reactive strength. Individualization of box heights for the athletes in the OPT group was according to protocols previously described (3, 22). Briefly, all athletes were asked to perform a maximal-effort vertical-oriented drop jump from fixed box heights of 10-cm, 20-cm, 30-cm, 40-cm, and 50-cm. Athletes completed three attempts from each height.

Instructions to athletes were the same as those previously described for the 20-cm RSI. Participants in both groups were motivated to minimize ground contact time and to maximize jump height (i.e., RSI) (22). The drills, sets, repetitions, and progressions per week are indicated in table 2. In this way, players progressed from 48 jumps per leg during each session in the 1st week, toward 90 jumps per leg during each session in the 6th week of plyometric training, with a taper during the 7th week (i.e., same volume as in the 1st week). A coach at a participant ratio of 1:3 supervised all training sessions and particular attention was paid to technique (i.e., overload was not applied until players achieve adequate technique). Senior physical education students, previously trained in this type of intervention, served as coaches. Plyometric sessions were performed just after the warm-up. The two plyometric training groups completed the same number of total repetitions during the intervention, using the same surface (i.e., grass soccer-field) and time of day (afternoon) for plyometric training, with the same rest intervals between sessions (i.e., 48-120 h, Tuesday and Thursday), drills sets (i.e., ~60 s) (30) and jumps (i.e., ~5 s; all drill repetitions were performed acyclical).

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

Statistical Analysis

Data are presented as group mean values ± standard deviations. Analyses of variance (ANOVA) were used to detect differences between study groups in all variables at pre- and post-tests. Measures of dependent variables were analyzed in separate 3 (Groups) × 2 (Time: pre, post) ANOVA with repeated measures on Time. Post-hoc tests with Bonferroni-adjusted α were conducted to identify comparisons that were statistically significant. Effect sizes were determined by calculating Cohen's d values (9). Cohen's d describes the effectiveness of a treatment and determines whether a statistically significant difference is a difference of practical concern. Cohen's d values are classified as small ($d \leq 0.49$), medium ($d = 0.50$ to ≤ 0.79), and large effects ($d \geq 0.8$) (9). Statistical analyses were carried out with STATISTICA statistical package (Version 8.0; StatSoft, Inc, Tulsa, USA). Significance levels were set at $\alpha = 5\%$.

RESULTS

The reliability of assessments was determined using the intraclass correlation coefficient, and ranged from 0.87 to 0.98.

Before the intervention

No significant differences were found between groups at baseline in any of the examined variables (Table 1 and Table 3). The main effects of group, time and group/time interaction are presented in table 3.

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

Training-induced effects on physical fitness

The analyses revealed significant main effects of time for all dependent variables ($p<0.001$, $d=0.24-0.72$), except for 20-m sprint time. Our analyses also revealed significant group × time interactions for CMJ ($p<0.001$, $d=0.51$), DJ ($p<0.001$, $d=0.30$), sprint time ($p<0.001$, $d=0.25$), CODT ($p<0.001$, $d=0.22$), and 5RM ($p<0.01$, $d=0.16$).

The post-hoc analyses revealed significant increases for the FIXED group (CMJ: 7.4%, d=0.36; DJ: 19.2%, d=0.49; CODA: -3.1%, d=-0.21; 5RM: 10.5%, d=0.32) and the OPT group (CMJ: 16.7%, d=0.76; DJ: 36.1%, d=0.79; CODA: -4.4%, d=-0.34; 5RM: 18.1%, d=0.47). Post-hoc analyses also revealed significant increases for the OPT group in 20-m sprint time (-3.7%, d=0.27).

DISCUSSION

The aim of this study was to compare the effects of maximal-effort vertical-oriented jump training with “fixed drop box” (i.e., 30-cm) versus “optimal drop box” (i.e., based on the highest individual RSI values) on the athletic performance of youth soccer players. As hypothesized, both plyometric training approaches improved youth soccer players’ athletic performance proxies, with greater improvements in the OPT group as compared to the Control group.

To our knowledge, this is the first randomized controlled trial that investigated the effects of vertical-oriented plyometric drop jump training performed with maximal effort from optimal compared to fixed box heights on proxies of athletic performance in youth soccer players. From these results, it can be suggested that, to maximize the benefits derived from maximal-effort vertical-oriented drop jumps, the plyometric training intervention should be based on individual parameters. Individualization may be achieved through determination of the box drop height that allow athletes to develop their optimal reactive strength during jumping (22). However, this might be unpractical when working with large groups of subjects, as the process is time-consuming and repeated measures may be necessary to determine the best RSI values over time. Additionally, individualization of drop heights usually requires a great number of boxes with different heights, which may be expensive, and sometimes difficult for coaches to acquire. To solve this impracticality, current results suggest that drop jump plyometric training performed with maximal effort from a box with moderate-height (i.e., 30-cm) may induce significant improvements in athletic performance in young soccer players. Although lower than the increases achieved with optimal drop heights, these positive changes might still be of meaningful relevance. In this sense, the intention to perform explosively in the concentric phase of an eccentric-dominant drill such as the drop jump may have played a key role during the training period (17). Therefore, prescription of maximal-effort drop jumps, independent of box height, would probably allow meaningful adaptations in athletic performance proxies of young soccer athletes. It must be considered that drop jumps in the current training intervention were performed according to previous suggestions (22), as any box height exceeded subjects' maximal jumping capabilities (mean countermovement jump ability ~30-cm).

Both plyometric training groups improved vertical jump performance (i.e., countermovement jump; 20-cm DJ), as compared to the control group. Although previous studies showed that plyometric jump training may improve jumping performance in youth soccer players (6, 23), the current novel experimental approach demonstrated that both optimal and fixed box heights improve jumping performance during drop jump-based plyometric training, with greater meaningful improvements using the former training approach. Adaptations such as an increase in muscle activation (25), activation rates, twitch torque, and reduced electro-mechanical delay (18), and improved intermuscular coordination (20) may facilitate rapid and maximal force production, thus jumping performance. In addition, a better utilization of the SSC properties of agonist muscles, greater muscle size, and possible fast-twitch muscle fibers increases may also lead to greater jumping ability (20, 41). Of note, the 20-cm RSI was significantly higher only for the OPT group compared to the Control group. In addition, the CMJ was meaningfully improved for the OPT group (effect size = 0.76) compared to the Control group (effect size = 0.36). The greater improvement in the OPT group may be related to the use of an optimal and specific box drop height during maximal-effort vertical drop jumps, leading to a greater jumping and RSI development (22).

Regarding CODA, as with jumping ability, both plyometric training groups improved performance as compared to the Control-group. The CODA gains have been previously observed after plyometric training in youth soccer players (4). However, the effects of drop jump-based plyometric training using optimal versus fixed drop boxes is reported in this manuscript for the first time. Several mechanism may help explain CODA improvements, some of which may be related with the previously discussed improvements in jumping performance, in addition to reactive and eccentric strength (39). The plyometric training interventions implemented in the current study were in accordance with previous recommendations (4, 5). However, improvements (i.e., d = 0.21 - 0.34) were somewhat lower those previously reported (4, 5). As mentioned above, as the jump-training stimulus was only vertically oriented, this may have reduced the magnitude of adaptation considering the horizontal force production requirement during CODA.

The absence of improvement in 20-m sprint performance in the FIXED group as compared to the Control group after the current plyometric training suggests that, aside from vertical drop-jumps, other training stimuli might be necessary to enhance the maximal sprinting ability of youth soccer players. A lack of change in sprint time after vertical drop jump–based plyometric training has been previously reported in youth soccer players (40). Given the role of horizontal force-production and its application in sprint performance (26), the incorporation of horizontally oriented plyometric training might help to improve sprint performance (33). However, current results revealed significant increases for the OPT group in the 20-m sprint time test compared to the Control-group. Although horizontal force orientation is paramount for sprint performance, application of force and power in the vertical axis is also of significance for sprinting speed (21). In this sense, it is interesting to hypothesize that given the use of optimal vertical-oriented reactive-strength index during training in the OPT group, this may have induced meaningful sprinting adaptations, leading to better utilization of reactive strength during sprinting, particularly during vertical application of force and power.

Maximal strength (5RM) was also improved after plyometric training in both the OPT (d = 0.47) and the FIXED (d = 0.32) plyometric training groups. Both plyometric training groups improved performance as compared to the Control-group. Plyometric training seems to be an effective strategy to improve maximal strength (38), Therefore, considering the relationship between maximal strength and key elements of explosive performance in soccer (43), the inclusion of plyometric training into the regular schedules of youth soccer players appears to be an adequate and effective strategy. Of note, both OPT and FIXED plyometric training groups improved maximal strength similarly, which may be related to the same surface type used to train (i.e., grass field), as the restitution coefficient of the surface type may play a significant role in adaptations induced by plyometric training, particularly in maximal strength (31).

Previous research have demonstrated the positive effects of plyometrics in endurance capabilities of youth soccer players (32, 33). In this sense, it was expected to observe an enhancement in endurance capabilities in both plyometric training groups, especially in the OPT group. However, this was not the case. Further research should be conducted to clarify this issue. Regarding kicking ability, previous studies demonstrated that a combination of unilateral and bilateral (32) or vertical and horizontal (12, 33) plyometric exercises may increase kicking ability in soccer players. However, in the current study no significant increases for the plyometric training groups were observed for kicking performance as compared to the Control-group.

Probably, the development of optimal reactive strength during plyometric training sessions is not as important as the combination of specific (kicking) drills (i.e., training variability) (32, 33). On the other side, previous studies have also indicated an improved kicking ability after bilateral-only and vertical-only plyometric training programs (30, 35). However, in those studies subjects had a reduced soccer-specific training load (i.e., two, compared to four soccer training sessions per week) or a reduced training level-age (i.e., Tanner score 1.3, compared to 3.5) (24) compared with the current study. In this sense, it is worth noting that our subjects had a greater time devoted to technical ability training, thus their kicking ability was more closest to their maximal age-potential, therefore with reduced possibilities to improve this specialized motor skill after "non-specific" plyometric training interventions.

In conclusion, to maximize the benefits derived from maximal-effort vertical-oriented drop jump plyometrics, training individualization based on the highest RSI values is advised, in order to enhance the development of optimal reactive strength. Nonetheless, the use of fixed moderate-height boxes may also provide a rational and practical alternative to improve athletic performance in youth soccer players.

PRACTICAL APPLICATION

The plyometric training program applied induced improvements on measures of physical fitness in young soccer players, which may have transference into game-play performance. Thus, a twice weekly short-term high-intensity plyometric training program, implemented as a substitute for some soccer drills within regular in-season soccer practice, can enhance measures of physical fitness in young soccer players compared with soccer training alone, and these improvements can be maximized if plyometric jump training is individualized based on the highest RSI values achieved during jump drills. Although is advised that PJT be conducted whenever possible on an individualized base, nonetheless, the use of fixed moderate-height boxes may also provide a rational and practical alternative to improve athletic performance in youth soccer players.

Although plyometric training can induce an increase on measures of physical fitness in young soccer players, to optimize training adaptations, this training strategy should be adequately applied in a more complex training plan that incorporates other explosive (e.g., sprints), endurance, technical, and tactical-oriented training methods.

REFERENCES

1. Altmann S, Hoffmann M, Kurz G, Neumann R, Woll A, and Haertel S. Different Starting Distances Affect 5-m Sprint Times. *J Strength Cond Res* 29: 2361-2366, 2015.
2. Andrade DC, Henriquez-Olguin C, Beltran AR, Ramirez MA, Labarca C, Cornejo M, Alvarez C, and Ramirez-Campillo R. Effects of general, specific and combined warm-up on explosive muscular performance. *Biol Sport* 32: 123-128, 2015.
3. Andrade DC, Manzo O, Beltrán AR, Alvares C, Del Río R, Toledo C, Moran J, and Ramirez-Campillo R. Kinematic and neuromuscular measures of intensity during plyometric jumps. *Journal of Strength and Conditioning Research*, IN PRESS.
4. Asadi A, Arazi H, Ramirez-Campillo R, Moran J, and Izquierdo M. Influence of Maturation Stage on Agility Performance Gains After Plyometric Training: A Systematic Review and Meta-analysis. *J Strength Cond Res* 31: 2609-2617, 2017.
5. Asadi A, Arazi H, Young WB, and Saez de Villarreal E. The effects of plyometric training on change-of-direction ability: A meta-analysis. *Int J Sports Physiol Perform* 11: 563-573, 2016.
6. Bedoya AA, Miltenberger MR, and Lopez RM. Plyometric training effects on athletic performance in youth soccer athletes: A systematic review. *J Strength Cond Res* 29: 2351-2360, 2015.
7. Bobbert MF, Huijing PA, and van Ingen Schenau GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Med Sci Sports Exerc* 19: 332-338, 1987.
8. Bobbert MF, Huijing PA, and van Ingen Schenau GJ. Drop jumping. II. The influence of dropping height on the biomechanics of drop jumping. *Med Sci Sports Exerc* 19: 339-346, 1987.

9. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, N.J. : Lawrence Erlbaum, 1988.

10. Chmielewski TL, George SZ, Tillman SM, Moser MW, Lentz TA, Indelicato PA, Trumble TN, Shuster JJ, Cicuttini FM, and Leeuwenburgh C. Low- versus high-intensity plyometric exercise during rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med* 44: 609-617, 2016.

11. Gail S and Künzell S. Reliability of a 5-Repetition Maximum Strength Test in Recreational Athletes. *Dtsch Z Sportmed* 65: 314-317, 2014.

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

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

14. Harriss DJ and Atkinson G. Ethical Standards in Sport and Exercise Science Research: 2016 Update. *Int J Sports Med* 36: 1121-1124, 2015.

15. Haugen TA, Tonnessen E, Svendsen IS, and Seiler S. Sprint time differences between single- and dual-beam timing systems. *J Strength Cond Res* 28: 2376-2379, 2014.

16. Ilić V, Mudrić M, Kasum G, Ćirković M, and Gavrilović D. Morphological and motor characteristics of young judokas. *Physical culture* 66: 110-118, 2012.

17. Kawamori N and Newton RU. Velocity Specificity of Resistance Training: Actual Movement Velocity Versus Intention to Move Explosively. *Strength & Conditioning Journal* 28: 86-91, 2006.

18. Legerlotz K, Marzilger R, Bohm S, and Arampatzis A. Physiological Adaptations following Resistance Training in Youth Athletes-A Narrative Review. *Pediatr Exerc Sci* 28: 501-520, 2016.

19. Markovic G, Dizdar D, and Jaric S. Evaluation of tests of maximum kicking performance. *J Sports Med Phys Fitness* 46: 215-220, 2006.

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

21. Marques MC, Gil H, Ramos RJ, Costa AM, and Marinho DA. Relationships between vertical jump strength metrics and 5 meters sprint time. *J Hum Kinet* 29: 115-122, 2011.

22. McGuigan MR, Cormack SJ, and Gill ND. Strength and Power Profiling of Athletes: Selecting Tests and How to Use the Information for Program Design. *Strength & Conditioning Journal* 35: 7-14, 2013.

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

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

25. Mirzaei B, Norasteh AA, and Asadi A. Neuromuscular adaptations to plyometric training: depth jump vs. countermovement jump on sand. *Sport Sciences for Health* 9: 145-149, 2013.

26. Morin JB, Gimenez P, Edouard P, Arnal P, Jimenez-Reyes P, Samozino P, Brughelli M, and Mendiguchia J. Sprint Acceleration Mechanics: The Major Role of Hamstrings in Horizontal Force Production. *Frontiers in physiology* 6: 404, 2015.

27. Myers AM, Beam NW, and Fakhoury JD. Resistance training for children and adolescents. *Translational pediatrics* 6: 137-143, 2017.

28. Peng HT, Kernozek TW, and Song CY. Quadricep and hamstring activation during drop jumps with changes in drop height. *Phys Ther Sport* 12: 127-132, 2011.

29. Radnor JM, Oliver JL, Waugh CM, Myer GD, Moore IS, and Lloyd RS. The Influence of Growth and Maturation on Stretch-Shortening Cycle Function in Youth. *Sports Medicine*, 2017.

30. Ramirez-Campillo R, Andrade DC, Alvarez C, Henriquez-Olguin C, Martinez C, Baez-Sanmartin E, Silva-Urra J, Burgos C, and Izquierdo M. The effects of interset rest on adaptation to 7 weeks of explosive training in young soccer players. *J Sports Sci Med* 13: 287-296, 2014.

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

32. Ramirez-Campillo R, Burgos CH, Henriquez-Olguin C, Andrade DC, Martinez C, Alvarez C, Castro-Sepulveda M, Marques MC, and Izquierdo M. Effect of unilateral, bilateral, and combined plyometric training on explosive and endurance performance of young soccer players. *J Strength Cond Res* 29: 1317-1328, 2015.

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

34. Ramirez-Campillo R, Henriquez-Olguin C, Burgos C, Andrade DC, Zapata D, Martinez C, Alvarez C, Baez EI, Castro-Sepulveda M, Penailillo L, and Izquierdo M. Effect of progressive volume-based overload during plyometric training on explosive and endurance performance in young soccer players. *J Strength Cond Res* 29: 1884-1893, 2015.

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

36. Ramirez-Campillo R, Meylan CM, Alvarez-Lepin C, Henriquez-Olguin C, Martinez C, Andrade DC, Castro-Sepulveda M, Burgos C, Baez EI, and Izquierdo M. The effects of interday rest on adaptation to 6 weeks of plyometric training in young soccer players. *J Strength Cond Res* 29: 972-979, 2015.

37. Rosas F, Ramirez-Campillo R, Diaz D, Abad-Colil F, Martinez-Salazar C, Caniuqueo A, Canas-Jamet R, Loturco I, Nakamura FY, McKenzie C, Gonzalez-Rivera J, Sanchez-Sanchez J, and Izquierdo M. Jump Training in Youth Soccer Players: Effects of Haltere Type Handheld Loading. *Int J Sports Med* 37: 1060-1065, 2016.

38. Saez-Saez de Villarreal E, Requena B, and Newton RU. Does plyometric training improve strength performance? A meta-analysis. *J Sci Med Sport* 13: 513-522, 2010.

39. Sheppard JM and Young WB. Agility literature review: Classifications, training and testing. *J Sport Sci* 24: 919-932, 2006.

40. Thomas K, French D, and Hayes PR. The effect of two plyometric training techniques on muscular power and agility in youth soccer players. *J Strength Cond Res* 23: 332-335, 2009.

41. Vissing K, Brink M, Lonbro S, Sorensen H, Overgaard K, Danborg K, Mortensen J, Elstrom O, Rosenhoj N, Ringgaard S, Andersen JL, and Aagaard P. Muscle adaptations to plyometric vs. resistance training in untrained young men. *J Strength Cond Res* 22: 1799-1810, 2008.

42. Weeks BK and Beck BR. The Relationship between Physical Activity and Bone during Adolescence Differs according to Sex and Biological Maturity. *J Osteoporos* 2010: 546593, 2010.

43. Wisloff U, Castagna C, Helgerud J, Jones R, and Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38: 285-288, 2004.

44. Yanci J, Los Arcos A, Camara J, Castillo D, Garcia A, and Castagna C. Effects of horizontal plyometric training volume on soccer players' performance. *Research in sports medicine (Print)* 24: 308-319, 2016.