# Optimal Reactive Strength Index: Is It an Accurate Variable to Optimize Plyometric Training Effects on Measures of Physical Fitness in Young Soccer Players?

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## Abstract

Ramirez-Campillo, R, Alvarez, C, García-Pinillos, F, Sanchez-Sanchez, J, Yanci, J, Castillo, D, Loturco, I, Chaabene, H, Moran, J, and Izquierdo, M. Optimal reactive strength index: is it an accurate variable to optimize plyometric training effects on measures of physical fitness in young soccer players? *J Strength Cond Res* 32(4): 885–893, 2018—This study aimed to compare the effects of drop-jump training using a fixed drop-box height (i.e., 30-cm [FIXED]) vs. an optimal (OPT) drop-box height (i.e., 10-cm to 40-cm: generating an OPT reactive strength index [RSI]) in youth soccer players' physical fitness. Athletes were randomly allocated to a control group ($n = 24$; age = 13.7 years), a fixed drop-box height group (FIXED, $n = 25$; age = 13.9 years), or an OPT 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], 5 multiple bounds), speed (20-m sprint time), change of direction ability (CODA [Illinois test]), strength {RSI and 5 maximal squat repetition test (5 repetition maximum [RM])}, 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 ($p < 0.001$, $d = 0.51$), depth jump (DJ) ($p < 0.001$, $d = 0.30$), 20-m sprint time ($p < 0.001$, $d = 0.25$), CODA ($p < 0.001$, $d = 0.22$), 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, change of direction, jumping

## Introduction

Previous findings revealed that plyometric jump training (PJT) increases tendon stiffness, which allows for 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, change of direction ability (CODA) ability, muscular

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endurance, and maximal strength (6,31,37). In fact, scientific data have indicated that PJT is an effective and safe training method for soccer players (6), which 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 has 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 (CMJ) 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 OPT 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 OPT drop-box height group. Before and after 7 weeks of training, tests for the assessment of jumping, sprinting, CODA, strength, endurance, and kicking ability were undertaken.

### Subjects

Seventy-three national-level young male soccer players (age, 10.9–15.9 years) were recruited from a professional soccer academy. At recruitment and during the in-season training period (midpart of the in-season), players completed 4 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 1 of 3 groups: fixed drop-box height group (FIXED, $n = 25$), OPT 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 (1,2), defenders (6–8), midfielders (7,7,9), 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 CG 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: (a) 2 years of systematic soccer training and competition, (b) free of musculoskeletal injuries during the past 6 months, (c) no systematic plyometric and strength training experience in the previous 5 months, and (d) attendance to ≥90% of all training sessions during the intervention.

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 CG ($\Delta = 0.5$ cm; $SD = 1.1$) or to a short-term plyometric training ($\Delta = 2.6$ cm; $SD = 1.6$) 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 $\alpha = 0.05$ (i.e., assumed type I error), using an effect size of 0.2.

Participants (and the respective parents or guardians of subjects under the age of 18) 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 conducted 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 University of Los Lagos.

### Procedures

Participants were accustomed to procedures (six 15-minute learning sessions during 2 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 hours 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 (a) have a good

**Table 1.** Participants' characteristics.* ± *SD*

| | FIXED ($n$ = 25) | OPT ($n$ = 24) | Control ($n$ = 24) |
|---|---|---|---|
| Age (y) | 13.9 ± 1.9 | 13.1 ± 1.7 | 13.7 ± 1.6 |
| Genital stage (1–5) | 3.7 ± 1.0 | 3.6 ± 1.2 | 3.8 ± 0.9 |
| Pubic hair stage (1–5) | 3.6 ± 1.1 | 3.4 ± 1.2 | 3.7 ± 0.9 |
| Stature (m) | 1.53 ± 0.1 | 1.53 ± 0.1 | 1.55 ± 0.1 |
| Body mass (kg) | 46.7 ± 10.5 | 47.2 ± 11.5 | 49.1 ± 11.1 |
| Body mass index (kg·m$^{-2}$) | 19.8 ± 2.0 | 19.8 ± 1.9 | 20.1 ± 2.1 |

*FIXED = drop-jump training using a fixed drop-box height; OPT = optimal reactive strength stimulation group.

night's sleep (≥8 hours) before each testing day, (b) have a meal rich in carbohydrates, and (c) 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 3-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, CMJ, 5 multiple bounds test, and the 20-cm drop-jump RSI test were completed. In addition, athletes were assessed for OPT box height for development of OPT reactive strength (see Training program section for details). On the second day, the 20-m sprint, CODA, and the 2.4-km time trial run endurance test were conducted. On the third day, the maximal kicking ability and the 5 repetition maximum (RM) squat tests were scheduled. The best score from 3 attempts was recorded for all performance tests, apart from the single 2.4-km time trial run and the 5RM squat tests. A rest interval of at least 2 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 CODA drills) 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 2 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. Last, 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 the 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 1 foot. Then, athletes performed a set of 4 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 seconds 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), 2 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 CODA 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).

**Table 2.** Plyometric jump training program.*

| | FIXED | | OPT | |
|---|---|---|---|---|
| Week 1 | Drop jumps from 30-cm box height | 6 × 8 | Drop jumps from optimal box height | 6 × 8 |
| Week 2 | | 6 × 9 | | 6 × 9 |
| Week 3 | | 6 × 10 | | 6 × 10 |
| Week 4 | | 9 × 8 | | 9 × 8 |
| Week 5 | | 9 × 9 | | 9 × 9 |
| Week 6 | | 9 × 10 | | 9 × 10 |
| Week 7 | | 6 × 8 | | 6 × 8 |

*FIXED = drop-jump training using a fixed drop-box height; OPT = optimal reactive strength stimulation group.

*Endurance Performance.* For the 2.4-km time trial run test, athletes completed a warm-up of 800-m and 4 minutes of rest. After that, athletes performed 6 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 1 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 5 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 2 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 $km \cdot h^{-1}$, 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.* It was assessed using concentric-eccentric 5RM parallel squat action. The assessments were completed using free weights (after athletes had participated in 6 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 5 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 1 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 5 separate attempts to find their 5RM. The last acceptable 5 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 has been previously established (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 midportion of the player's competition period. The CG did not perform the plyometric training but performed their usual soccer training (i.e., mainly technical-tactical, small-sided and simulated games, and 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-minute training, twice per week, and 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 CMJ performance

**TABLE 3.** Mean and *SD* of outcome measures for each group before (Pre) and after (Post) the intervention period.*

| | FIXED ($n = 25$) | | OPT ($n = 24$) | | Control ($n = 24$) | | ANOVA outcomes | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Group: $F(2, 70)$, $p$ ($d$) | Time: $F(1, 70)$, $p$ ($d$) | Group × time: $F(2, 70)$, $p$ ($d$) |
| CMJ (cm) | 27.9 ± 5.4 | 29.9 ± 5.7 | 27.6 ± 5.6 | 31.8 ± 5.4 | 27.8 ± 4.8 | 28.4 ± 4.1 | $F = 0.6$, $p = 0.56$ (0.02) | $F = 185.3$, $p < 0.001$ (0.72) | $F = 37.2$, $p < 0.001$ (0.51) |
| 20-cm RSI ($ms \cdot ms^{-1}$)† | 1.1 ± 0.5 | 1.3 ± 0.5 | 1.1 ± 0.5 | 1.5 ± 0.5 | 1.1 ± 0.5 | 1.2 ± 0.4 | $F = 1.1$, $p = 0.33$ (0.03) | $F = 97.3$, $p < 0.001$ (0.57) | $F = 15.9$, $p < 0.001$ (0.30) |
| Five multiple bounds (m) | 8.83 ± 1.3 | 8.99 ± 1.3 | 8.90 ± 1.2 | 9.18 ± 1.0 | 8.84 ± 1.3 | 8.98 ± 1.3 | $F = 0.1$, $p = 0.92$ (0.00) | $F = 23.1$, $p < 0.001$ (0.24) | $F = 1.1$, $p = 0.35$, (0.03) |
| 20-m sprint time (s) | 4.36 ± 0.5 | 4.43 ± 0.5 | 4.35 ± 0.6 | 4.19 ± 0.6 | 4.35 ± 0.5 | 4.41 ± 0.5 | $F = 0.4$, $p = 0.65$ (0.01) | $F = 0.3$, $p = 0.60$ (0.00) | $F = 12.0$, $p < 0.001$ (0.25) |
| Change of direction speed time test (s) | 20.4 ± 1.9 | 19.8 ± 1.7 | 20.3 ± 1.7 | 19.4 ± 1.3 | 20.2 ± 1.7 | 20.0 ± 1.6 | $F = 0.1$, $p = 0.92$ (0.00) | $F = 67.3$, $p < 0.001$ (0.48) | $F = 10.1$, $p < 0.001$ (0.22) |
| 5 maximum-repetition squat test (kg) | 31.2 ± 9.4 | 34.5 ± 10.7 | 31.8 ± 11.0 | 37.2 ± 11.8 | 31.9 ± 9.1 | 33.2 ± 10.2 | $F = 0.3$, $p = 0.77$ (0.01) | $F = 55.3$, $p < 0.001$ (0.43) | $F = 6.7$, $p < 0.01$ (0.16) |
| 2.4-km time trial (min) | 10.5 ± 0.9 | 10.3 ± 1.0 | 10.4 ± 0.8 | 10.1 ± 0.8 | 10.5 ± 0.8 | 10.3 ± 0.7 | $F = 0.4$, $p = 0.65$ (0.01) | $F = 55.4$, $p < 0.001$ (0.43) | $F = 2.1$, $p = 0.14$ (0.05) |
| Maximal kicking distance (m) | 40.8 ± 5.6 | 41.0 ± 6.4 | 38.8 ± 6.1 | 39.7 ± 8.3 | 39.8 ± 5.8 | 40.2 ± 5.5 | $F = 0.2$, $p = 0.85$ (0.00) | $F = 25.1$, $p < 0.001$ (0.26) | $F = 0.3$, $p = 0.77$ (0.01) |

*FIXED = drop-jump training using a fixed drop-box height; OPT = optimal reactive strength stimulation group; ANOVA = analysis of variance; *d* = Cohen's *d*; CMJ = countermovement jump; RSI = reactive strength index.

†The index is calculated as flight time divided by contact time.

of the group before the intervention, a 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 OPT 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, 20, 30, 40, and 50 cm. Athletes completed 3 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 first week, toward 90 jumps per leg during each session in the sixth week of plyometric training, with a taper during the seventh week (i.e., same volume as in the first 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 2 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 hours, Tuesday and Thursday), drills sets (i.e., ~60 seconds) (30), and jumps (i.e., ~5 seconds; all drill repetitions were performed acyclical).

### Statistical Analyses

Data are presented as group mean values ± *SD*s. Analyses of variance (ANOVAs) were used to detect differences between study groups in all variables at pretests and posttests. Measures of dependent variables were analyzed in separate 3 (groups) × 2 (time: pre and post) ANOVA with repeated measures on time. Post hoc tests with Bonferroni-adjusted $\alpha$ 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 $\leq 0.79$), and large effects ($d \geq 0.8$) (9). Statistical analyses were performed with STATISTICA statistical package (Version 8.0; StatSoft, Inc., Tulsa, OK, 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 (Tables 1 and 3). The main effects of group, time, and group/time interaction are presented in Table 3.

### 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 ($p < 0.001$, $d = 0.51$), depth jump (DJ) ($p < 0.001$, $d = 0.30$), sprint time ($p < 0.001$, $d = 0.25$), CODA test ($p < 0.001$, $d = 0.22$), 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) vs. "OPT 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 CG.

To the best of 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 OPT compared with 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 OPT 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. In addition, 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 OPT 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 for 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 CMJ ability ~30 cm).

Both plyometric training groups improved vertical jump performance (i.e., CMJ; 20-cm DJ), as compared to the CG. Although previous studies showed that PJT may improve jumping performance in youth soccer players (6,23), the current novel experimental approach demonstrated that both OPT 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 electromechanical 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 with the CG. In addition, the CMJ was meaningfully improved for the OPT group (effect size = 0.76) compared with the CG (effect size = 0.36). The greater improvement in the OPT group may be related to the use of an OPT 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 CG. 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 OPT vs. fixed drop boxes are reported in this article for the first time. Several mechanisms 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 than 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 CG 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 with the CG. 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 OPT vertical-oriented RSI 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 CG. 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 seems 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 has 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 CG. Probably, the development of OPT 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., 2 compared with 4 soccer training sessions per week) or a reduced training level age (i.e., Tanner score 1.3, compared with 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, to enhance the development of OPT 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 Applications

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 PJT is individualized based on the highest RSI values achieved during jump drills. Although it 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.

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