

# Effects of Complex Training Using Ascending Versus Descending Exercise Sequence on Physical Fitness Measures of Male University Athletes: A Randomized Parallel Group Trial

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## Abstract

Saini, P, Halyi, N, Gogoi, H, Kharel, A, Baruah, J, and Thapa, RK. Effects of complex training using ascending versus descending exercise sequence on physical fitness measures of male university athletes: A randomized parallel group trial. *J Strength Cond Res* XX(X): 000–000, 2026—This study compared the effects of 6 weeks of complex-ascending (CAT; ballistic exercises before resistance exercises) vs. complex-descending training (CDT; resistance exercises before ballistic exercises) on physical performance measures. Twenty-five male university athletes were randomly assigned to either the CAT ( $n = 12$ ) or the CDT group ( $n = 13$ ). Pre- and postintervention assessments included countermovement jump (CMJ), squat jump (SJ), rebound jump, isometric midthigh pull, isometric squat, 1 repetition maximum squat, linear sprint (10, 20, 30 m), change-of-direction speed, standing long jump, and Yo-Yo intermittent recovery level 1. The main effect of time was observed for CMJ (i.e., jump height, absolute and relative peak power, reactive strength index, net impulse, unweighing duration, braking duration, propulsion duration, flight time, and take-off velocity), SJ (i.e., jump height, relative net peak force, absolute and relative peak power, net impulse, propulsion duration, flight time, take-off velocity), isometric midthigh pull and isometric squat net peak force, 1 repetition maximum squat, linear sprint times, change-of-direction speed, standing long jump, and Yo-Yo IRL1. Time  $\times$  group interaction effect was observed only for 1 repetition maximum squat ( $p = 0.017$ ;  $\eta p^2 = 0.252$ ). However, analysis of covariance with preintervention scores as covariates showed no between-group differences for any outcome variable ( $p = 0.058$ – $0.981$ ), except for CMJ absolute peak force ( $p = 0.034$ ;  $g = 0.61$ ), which favored CDT. In conclusion, both CAT and CDT were equally effective in improving CMJ, SJ, maximal dynamic and isometric strength, horizontal muscle power, and intermittent endurance. Practitioners working with male university athletes may select either sequencing based on training goals and logistical considerations.

**Key Words:** athletic performance, exercise order, force output, human physical conditioning, plyometric exercise, resistance training

## Introduction

Athletes engaged in high-intensity sports are required to repeatedly perform skilled actions and exert near-maximal-to-maximal effort (e.g., sprints, jumps, accelerations, changes of direction, and kicks) with brief recovery intervals (42). Therefore, complex physical demands are placed on the athlete, requiring them to develop speed, agility, muscular strength and power, and endurance (9,41). Moreover, athletes are required to maintain these qualities under fatigued conditions (33,34). Failing to meet these demands may increase an athlete's injury risk by compromising deceleration control, delaying force dissipation during high-speed directional changes, and reducing eccentric loading capacity, ultimately leading to substantial time loss from training and competition (14,49).

Both traditional resistance training (RT) and ballistic training (BT) have been proven to improve physical performance in athletic populations (albeit through different mechanisms) (25,40). RT involves lifting moderate to heavy loads (60–90% of 1 repetition maximum [1RM]) (37) and is primarily used to achieve significant increases in maximum strength and muscle hypertrophy (40). In contrast, BT encompasses high-velocity movements in which the body or an external load is projected into the flight phase (e.g., squat jumps [SJ], medicine ball throws) with the aim to minimize deceleration and maximize acceleration phase (29) and is more indicated to improve muscle power (9). Indeed, both RT and BT programs have been shown to enhance key physical parameters (e.g., maximum strength, jumping, endurance, linear sprinting, and change-of-direction ability) in different groups of athletes (including collegiate-level athletes) (3,20). Nevertheless, conducting independent training sessions for each method within a congested weekly microcycle may be troublesome for players and coaches, especially for university-level athletes with limited training times. To address these challenges, a rational approach to training could be to combine both RT and BT methods within a single training session (i.e., complex training [CT]), allowing more time to be devoted to sport-specific training (10).

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Compared with traditional RT or BT approaches that use a single training methodology, combining heavier (i.e., strength-oriented) and lighter (i.e., velocity-oriented) loads within the same session may promote adaptations across the components of the force-velocity curve (10). Indeed, recent meta-analyses reported that combining both in a CT format may induce performance adaptations, often exceeding those of single-mode training (44,47). Moreover, when programming CT, exercise sequencing may be vital to achieving the desired training outcome. For example, exercise sequences under CT are broadly categorized into 4 categories, namely, contrast, ascending, descending, and French-contrast (10). Although research is abundant in some form of CT (e.g., contrast), because of their specific claims (e.g., postactivation performance enhancement) (48), little is known about other formats of CT. For example, performing complex ascending training (CAT) (i.e., low-load BT exercise followed by high-load RT exercises) might be considered to promote neuromuscular adaptation in high velocity function, as there is minimal fatigue at the beginning of the workout, while enhancing a warming-up effect for the subsequent heavier load (10). Whereas in complex descending training (CDT) (i.e., high-load RT exercises followed by low-load BT exercises), the BT is performed at the end of the session when subjects are fatigued after the RT exercises (10).

Although a few studies have examined the acute effect of CT sequencing on performance in football and rugby players (2,12), longitudinal investigations comparing the 2 CT sequencing methods remain scarce. Only a single study (28) has compared the training effects of the 2 CT protocols (i.e., CAT vs. CDT) for performance enhancement of national-level male basketball players during the off-season period. The authors reported no between-group (CAT vs. CDT) differences in improvements for vertical jump (countermovement jump [CMJ], SJ, drop jump), change-of-direction speed (CODS), or linear sprint performance after 8 weeks of intervention (28). Of note, the study involved national-level basketball players during the off-season (28), and the results cannot be extrapolated to lesser-trained athletes, such as those at the university level. Therefore, the aim of this study was to compare the effects of CAT vs. CDT on physical fitness measures of male university athletes.

## Methods

### Experimental Approach to the Problem

The study was conducted in accordance with the updated CONSORT guidelines for reporting parallel-group randomized trials (38). A 2 (within-group: pre- and postintervention assessment) by 2 (between-group: CAT and CDT experimental groups) randomized study design was used to compare the effects of 6 weeks of CAT and CDT on selected physical fitness measures among male university athletes. The pre- and postassessment of physical fitness measures was conducted at similar times of day to avoid interference with circadian rhythm. The testing order was kept the same across both testing periods, with CMJ, SJ, and 10/5 repeated jumps (RJ) being conducted on day 1. The maximal effort isometric midthigh pull (IMTP) and isometric squat push (ISqt) were assessed on day 2. On day 3, CODS and linear sprint test were performed. The 1RM squat strength was measured on day 4. The standing long jump (SLJ) and Yo-Yo intermittent recovery level 1 (IRL1) test were conducted on day 5.

A 1-week familiarization session was conducted before the baseline data collection. The CAT and CDT protocols were

explained to subjects. Subjects' demographic details and anthropometric data were collected during these sessions. In addition, subjects were informed about the physical fitness tests and allowed to practice them to minimize the learning effect. Subjects were asked to avoid strenuous activity 24 hours before testing and to avoid heavy meals at least 3 hours before testing. They were advised to maintain their habitual eating and drinking habits before the testing session. In addition, the assessments were conducted after a minimum 48-hour rest period after the last training session to avoid fatigue-related effects.

### Subjects

The minimum number of subjects (i.e., sample size) was estimated using a statistical software G\*power (version 3.1.9.7, University of Düsseldorf, Düsseldorf, Germany). A priori sample size analysis indicated a total of 16 subjects (i.e., minimum 8 in each group) would be required to attain statistical significance with the following variables: F: test; ANOVA: repeated measures within-between interaction; two-tailed; correlation among rep measure = 0.5;  $\alpha$  error probability = 0.05; desired power ( $1-\beta$  error) = 0.90; no. of groups = 2 (CAT and CDT); no. of measurements = 2 (pre, post); effect size (ES) ( $f$ ) = 0.44 (converted from partial eta square value of 0.164 for 30-m linear sprint time) (35). Subjects were included if they (a) were aged between 18 and 25 years, (b) had a minimum of 1 year of respective sports training experience, (c) had a minimum of 1 year of RT (2–3 times-week<sup>-1</sup>) and BT experience, (d) be able to perform the RT exercises correctly with prior experience of 1RM testing, and (e) were physically active (>6 hours of activity-week<sup>-1</sup>). They were excluded if they (a) had any preexisting medical conditions that contraindicate high-intensity training, (b) had lower limb injuries from the past 6 months, or (c) were engaged in any other structured training programs.

Thereafter, a purposive convenience sampling method was used to recruit subjects for the study. Eligible subjects were stratified based on their sport participation and then randomly assigned to either of the 2 experimental groups using an online research randomizer tool (available at [www.randomizer.org](http://www.randomizer.org)) with a 1:1 allocation ratio. An independent researcher who was not involved in the training process conducted the randomization. The subjects and the researcher involved in the training were not aware until the start of the training intervention. The anthropometric and demographic details of the subjects are presented in Table 1. The study's associated benefits and risks were explained to all subjects before recruitment, and they signed the informed consent form. The study was approved by the Internal Review Board of Rashtriya Raksha University (Protocol number: RRU/SPES/IRB/2025-26/11) and was conducted in accordance with the latest Declaration of Helsinki. Subjects were excluded from the final evaluation if they attended fewer than 80% of the training sessions. The schematic representation of study subjects is presented in Figure 1.

### Training Intervention

The intervention lasted for 6 weeks. Both experimental groups underwent 2 weekly training sessions, separated by at least 48 hours to allow adequate recovery (i.e., 12 training sessions). The exercises were selected based on recommendations from previous studies (3,10). Four biomechanically similar RT and BT exercises were selected for complex exercises: back squats,

**Table 1**  
**Subject's anthropometric and demographic characteristics.**

Variables	Complex ascending training (n = 11)	Complex descending training (n = 13)	p
Age (y)	22.5 ± 1.4	22.8 ± 1.7	0.632
Height (cm)	164.7 ± 3.9	164.9 ± 6.1	0.929
Body mass before training (kg)	64.8 ± 6.4	67.9 ± 11.6	0.443
Body mass after training (kg)	62.8 ± 6.1	68.6 ± 11.9	0.161
Sports training experience (y)	7.8 ± 2.0	6.3 ± 2.8	0.150
Resistance training experience (y)	2.7 ± 1.2	1.4 ± 0.7	0.002*
Relative 1RM squat before training (kg·kg <sup>-1</sup> )	1.4 ± 0.2	1.3 ± 0.1	0.137

\*Significant difference between groups.

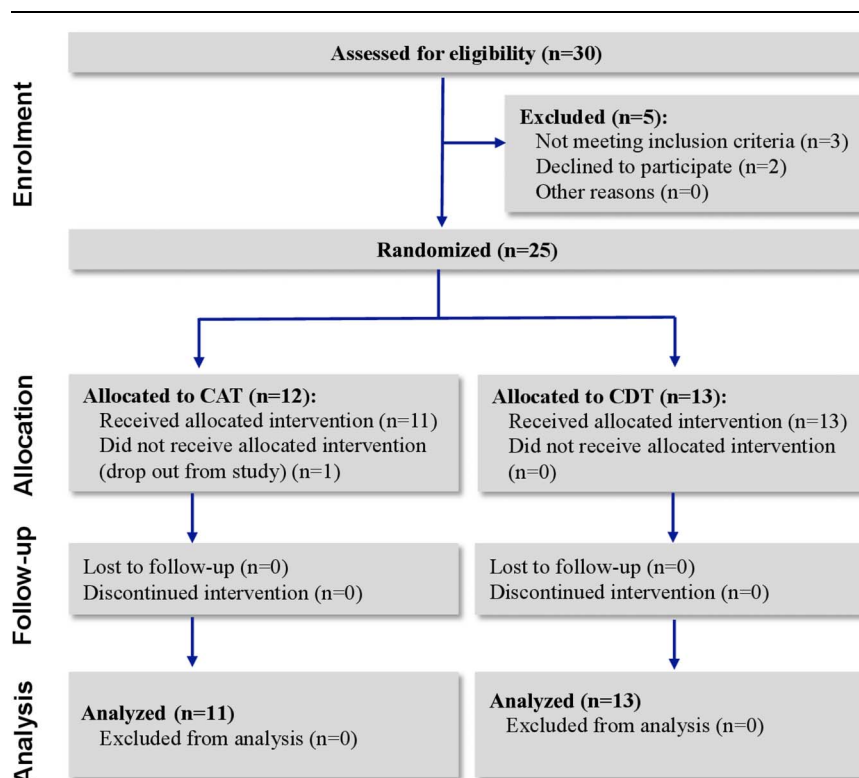
Bolded values represent statistically significant differences ( $p < 0.05$ ).

dumbbell lunges, deadlifts, and weighted calf raises as RT and CMJs, split jumps, standing broad jumps, and pogo jumps as BT exercises. The CDT group performed RT exercise sets (i.e., all sets of all exercises) first, followed by BT exercise sets. In contrast, the CAT group performed all BT exercise sets first, followed by RT exercise sets. The subjects were asked to perform both the high-load and low-load activities with the intention (i.e., effort) of attaining maximal velocity. During the training intervention period, both group subjects ( $n$ ; badminton = 3, boxing = 2, cricket = 1, soccer = 16, taekwondo = 1, wushu = 2) were involved in their regular sports-specific training (3 sessions·week<sup>-1</sup>) delivered by coaches of respective sports and physical education lessons but were not involved in any other kind of RT and BT. All training sessions started with a warm-up protocol of ~10 minutes that included light jogging, dynamic stretching of lower limb muscles, and warm-up sets of the following exercises (back squat, dumbbell lunge, deadlift, and standing calf raise) with an empty barbell or a lighter load. A 3-minute rest was allowed between RT exercise sets, whereas 90-second rest was

allowed during BT exercise sets. A 3-minute rest was provided between exercises. A typical session lasted ~90 minutes, including warm-ups. Postworkout subjects followed their habitual cool-down protocol. The detailed training intensity and volume used for intervention are mentioned in Table 2.

### Physical Fitness Assessment

The same researcher and assistants conducted the test protocols before and after the intervention and were blinded to the subjects' group allocation. Before each testing session, all subjects followed a 10-minute general warm-up routine that included running at a self-selected pace and dynamic lower limb stretching. Thereafter, subjects performed submaximal bouts of activities according to the test (e.g., submaximal CMJs, sprints, etc.) as a specific warm-up. Consistent verbal encouragements were provided to all subjects during each test trial. The sequence of subject testing on the testing day was kept similar at pre- and postintervention. The

**Figure 1.** Schematic representation of the study subjects using the CONSORT updated guidelines.

**Table 2**  
Description of training intensity and volume.

Week	Training day 1			Training day 2		
	Resistance exercise		Ballistic exercise	Resistance exercise		Ballistic exercise
	% 1 RM	Set × reps	Set × reps	% 1 RM	Set × reps	Set × reps
1	70	3 × 7	3 × 6	70	3 × 6	3 × 6
2	75	3 × 7	3 × 6	75	3 × 6	3 × 6
3	77	3 × 6	3 × 7	77	3 × 5	3 × 7
4	80	3 × 6	3 × 7	80	3 × 5	3 × 7
5	83	3 × 5	3 × 8	83	3 × 4	3 × 8
6	85	3 × 5	3 × 8	85	3 × 4	3 × 8

\*1RM = 1 repetition maximum; reps = repetitions.

jump and isometric tests were conducted on a portable force platform (K-Deltas, Kinvent Physio, Montpellier, France) with a sampling frequency of 2000 Hz, and the built-in starting threshold was set to 19.62 N for all assessments.

**Countermovement Jump.** The CMJ was conducted to assess the eccentric-concentric power (i.e., SSC) of the lower limb muscles on the vertical axis. The subjects began the CMJ at a self-selected depth and kept their hands on their hips. They were instructed to achieve maximum height without flexing their knees and removing their hands from their hips (36). If that occurred, the trial was rejected, and another trial was performed after the specified recovery period. Each subject did 3 trials with an interjump recovery duration of 3 minutes.

**Squat Jump.** The SJ was conducted to assess the concentric-only power of the lower limb muscles on the vertical axis. The subjects initiated the SJ from a static squat position, holding for 3 seconds to avoid eccentric movement while keeping their hands on their hips. They were instructed to achieve maximum height without flexing their knees and removing their hands from their hips. If that occurred, the trial was rejected, and another trial was performed after the specified recovery period. In addition, if there were any prestretch (i.e., eccentric movement) before the jump, the trial was automatically discarded by the force platform software. Each subject performed 3 trials with an interjump recovery duration of 3 minutes. The SJ variables were also recorded using the force platform.

**10/5 Repeated Jump.** The RJ was used to assess the reactive strength index (RSI) and was performed on the force platform. The subject began the RJ test with a CMJ, subsequently rebounding for 10 trials, aiming to achieve maximum jump height while minimizing ground contact time (GCT). The top 5 trials were selected to calculate the average RSI, modified RSI (mRSI), average GCT, average jump height, and average force. In addition, peak RSI and mRSI were also determined among the top 5 hops.

**Isometric Midthigh Pull.** The IMTP was conducted to measure maximal isometric strength of the posterior chain using the force platform. Subjects followed a standardized protocol, positioning the bar at midthigh with knee angles of 135–145° and hip angles of 140–150° measured using a hand-held goniometer (8). No straps were used, and foot placement was kept consistent across testing sessions. Each subject completed 2 maximal-effort trials, separated by a 3-minute rest. The test began with a countdown (“3, 2, 1, Go”), during which the subjects exerted maximal force for 5 seconds. To ensure consistency, subjects

received standardized verbal cues (i.e., “pull as fast and as hard as possible”) during all the trials.

**Isometric Squats.** To measure maximal isometric strength in the lower limb, the ISqt test was conducted using the force platform. Subjects adopted a squat stance with knees at ~120 (±10) degrees and pushed maximally against a fixed barbell at shoulder height, following the protocol described by Blazevich, Gill and Newton (5). Two maximum-effort trials were performed, with a 3-minute rest period, beginning with a standard 5-second countdown and using verbal cues similar to those in the IMTP protocol.

**Standing Long Jump.** The SLJ was performed to assess lower limb muscle power on the horizontal axis. The SLJ was conducted on an outdoor clay surface. The subjects stood behind the starting line, feet shoulder-width apart. They performed the jump with a self-selected countermovement, incorporating arm swings, and were instructed to jump as far as possible. The measurement was recorded using a standard measuring tape in meters, with an assistant, from the start line to the nearest point of contact on landing (i.e., the back of the heel of the nearest foot). The subjects performed 3 trials, with a 3-minute rest between trials.

**Change of Direction Speed.** The CODS was assessed using the 5-0-5 test on a natural grass surface. The subjects sprinted 10 m toward a marked line and performed a 180-degree turn (from the marked line) toward the starting line. One pair of timing gates (Witty, Microgate, Bolzano, Italy) was used to record the time in seconds. Two maximal-effort CODS trials were performed on each side, with a 3-minute recovery between trials.

**Linear Sprint.** The 30-m linear sprint test was conducted on an outdoor natural grass turf, with split times measured at each 10-m distance (i.e., at 10 and 20 m). Subjects were asked to stand at the start point (0.30 m behind the first timing gate) and use a self-selected start approach for the test. The sprint times were measured using electronic timing gates (Witty, Microgate, Bolzano, Italy). Two maximum-effort trials with an intertrial recovery period of 3 minutes were conducted.

**Dynamic Maximal Strength.** The maximal dynamic strength of the subjects was assessed using the 1RM squat. After a general warm-up, subjects performed a short specific warm-up consisting of 5–10 repetitions at 30–40% and 3–5 repetitions at 60–70% of the estimated 1RM. The weights were progressively increased through incremental sets, with 3–5 minutes of rest between attempts. The test continued until the subjects could no longer complete 1 full squat with proper form. Similarly, 3RM was calculated for dumbbell lunge, deadlift, and standing calf raise

only at baseline. The baseline assessment data were used to determine the training load. For maximal-strength analysis, only 1RM squat data was used.

**Yo-Yo Intermittent Recovery Test (Level 1).** The Yo-Yo intermittent recovery level 1 was conducted on a natural outdoor grass surface. A 20-m area was marked using cones, and 5 different lanes were created. A 5-m recovery zone was also prepared for each lane. A total of 5 subjects were tested together. The subjects started running after the first beep, and a warning beep was present in the middle of the total time allotted to complete the 40 m. The speed increased progressively, and audio instructions were present at every change in speed level. A 10-second recovery was allowed after every sprint. One warning was given if the subjects started early, or did not cross the turning line, or did not reach the starting line before the third beep. The second foul resulted in disqualification, and the score for the last lap was taken into consideration.

### Statistical Analyses

Data normality was verified using the Shapiro-Wilk test. Non-normally distributed data were transformed to normality using a two-step approach for parametric statistical analyses (43). Normally distributed data are presented as mean and standard deviation, whereas non-normally distributed data are presented as median and interquartile range. A parametric 2 (between-group: CAT and CDT) by 2 (within-group: pre- and postassessment) mixed ANOVA was used to analyze the interaction effect of intervention on dependent variables. In addition, ANCOVA with pretest score as covariate was computed to identify post-intervention difference between groups with the Bonferroni-adjusted unpaired *t* test. ES scores were calculated using partial eta squared ( $\eta_p^2$ ) for the interaction effect, interpreted as small ( $<0.06$ ), medium ( $\geq 0.06$ – $0.13$ ), and large ( $\geq 0.14$ ) (7). Within-group comparisons were computed using the Bonferroni-adjusted paired *t* test as post hoc analysis, and the magnitude of difference was computed using Hedges *g* ES. Hedges *g* ES was categorized as trivial ( $<0.2$ ), small ( $\geq 0.2$ – $0.6$ ), moderate ( $>0.6$ – $1.2$ ), or large ( $>1.2$ – $2.0$ ) (16). In addition, the percentage changes were calculated from pre- to postassessment for all variables in both groups. The between-trials reliability of the data was assessed using the intraclass correlation coefficient (ICC) with a 95% confidence interval (CI). The ICC was interpreted based on the lower bound of the CI as poor ( $<0.5$ ), moderate ( $0.5$ – $0.75$ ), good ( $0.75$ – $0.9$ ), and excellent ( $>0.9$ ) reliability (21). The data were analyzed using SPSS version 27.0.0 (IBM, New York). Statistical significance was set at  $p \leq 0.05$ .

### Results

The following variables were found to be non-normally distributed and were transformed into normal distribution using the 2-step approach: CMJ (relative peak force, absolute and relative net peak force, relative peak power, RSI, mRSI, propulsion and braking duration), SJ (relative peak force, absolute and relative net peak force), RJ (average height, average and peak RSI, average and peak mRSI, and average GCT), ISqt net peak force, 1RM squat, and Yo-Yo intermittent recovery level 1 distance for parametric analysis. The test-retest reliability was acceptable for all dependent variables; the ICCs with 95% CIs are presented in Supplemental Digital Content 1 (see Supplementary Material,

<http://links.lww.com/JSCR/A845>, <http://links.lww.com/JSCR/A846>). No significant differences were observed in subjects' age, height, body mass, and sports training history (Table 1). However, a large ( $g = 1.4$ ) significant difference in RT history was found between groups, despite random allocation. No training or testing-related injury was recorded. Further, only 1 subject attended  $<80\%$  training sessions. However, the subject was not excluded from the final analysis, as the sensitivity analysis exhibited no difference in results with or without exclusion. The results of all the analysis are presented in Table 3.

### Main Effect of Time

The main effect of time was observed for CMJ (i.e., jump height, absolute and relative peak power, RSI, net impulse, unweighing duration, braking duration, propulsion duration, flight time, and take-off velocity), SJ (i.e., jump height, relative net peak force, absolute and relative peak power, net impulse, propulsion duration, flight time, take-off velocity), IMTP and ISqt net peak force, 1RM squat, linear sprint times, CODS, SLJ, and Yo-Yo IRL1. No main effect of time was observed for absolute and relative peak and net peak force, mRSI during CMJ, absolute and relative peak force, and absolute net peak force during SJ, and all RJ variables. Furthermore, a graphical representation of the within-group percentage change from pre- to postintervention is presented in Figure 2.

### Between-Groups Changes

The time  $\times$  group interaction revealed significant effects only for 1RM squat strength ( $F = 6.73$ ;  $p = 0.017$ ;  $\eta_p^2 = 0.252$ ). Furthermore, comparisons of post-test values between groups with baseline performance and RT experience (because a significant difference was observed after randomization) as covariate demonstrated significant differences in CMJ absolute peak force ( $F = 5.192$ ;  $p = 0.034$ ;  $g = 0.61$ ), favoring CDT. No significant differences were observed in any other variable ( $p = 0.058$ – $0.981$ ).

### Discussion

This study aimed to compare the sequencing effects of RT and BT in CAT vs. CDT format over a 6-week intervention period on CMJ, SJ, and RJ kinematics and kinetics, and maximal strength, linear sprint, CODS, and endurance-related performance variables in university-level male athletes. The primary findings suggest that both CT sequencing formats were effective in improving vertical jump performance, maximal strength, horizontal jump, and intermittent endurance. However, linear sprint performance improved only in the CAT group, whereas CODS ability improved only in the CDT group. Of note, after adjusting for covariates, there were no significant differences in any variable, except for CMJ absolute peak force.

The improvements after CT intervention are consistent with prior research on CT, which indicates improvements in jumps, sprints, CODS, and maximal strength across various athletic and nonathletic populations (4,45–47). These improvements may be attributed to structural and neuromuscular adaptations similar to RT and PT, including improved stretch-shortening cycle, rate coding, increased motor unit recruitment (especially fast-twitch fibers), hormonal milieu, inter- and intramuscular coordination, and morphological changes (e.g., hypertrophy, muscle-tendon stiffness) that help in force generation capability (6,9,45,46).

**Table 3**  
**Statistical analysis within- and between-groups for all dependent variables.**

Variable	Complex ascending group			Complex descending group			Main effect time	Interaction effect time × group	ANCOVA
	Pretest†	Post-test†	Hedges <i>g</i>	Pretest†	Post-test†	Hedges <i>g</i>	<i>p</i> ( $\eta_p^2$ )	<i>p</i> ( $\eta_p^2$ )	<i>p</i> ( $\eta_p^2$ )
<b>Countermovement jump</b>									
Jump height (cm)	31.2 ± 4.3	34.3 ± 4.5‡	1.30 <sup>L</sup>	27.2 ± 4.0	29.9 ± 4.5‡	0.96 <sup>M</sup>	<0.001 (0.61)	0.697 (0.01)	0.981 (<0.01)
Absolute PF (N)	1659.7 ± 287.2	1646.1 ± 250.3	0.05 <sup>T</sup>	1579.8 ± 329.6	1665.0 ± 290.5§	0.53 <sup>S</sup>	0.401 (0.03)	0.251 (0.06)	<b>0.034</b> (0.22)
Relative PF (N·kg <sup>-1</sup> )	25.7 ± 3.0	26.1 ± 3.9	0.13 <sup>T</sup>	22.8 (2.6)	24.9 ± 1.4	0.60 <sup>S</sup>	0.095 (0.13)	0.306 (0.05)	0.335 (0.05)
Absolute NPF (N)	929.7 (316.1)	1018.1 ± 201.0	0.06 <sup>T</sup>	796.2 (301.0)	1000.8 ± 168.9	0.59 <sup>S</sup>	0.258 (0.07)	0.155 (0.10)	0.265 (0.07)
Relative NPF (N·kg)	16.5 (4.2)	15.4 (4.2)	0.26 <sup>S</sup>	15.0 ± 1.7	12.9 (2.4)	0.47 <sup>S</sup>	0.580 (0.02)	0.087 (0.15)	0.245 (0.08)
Absolute peak power (W)	3089.6 ± 415.8	3288.8 ± 372.8‡	0.70 <sup>M</sup>	2921.2 ± 493.9	3120.3 ± 493.2‡	0.61 <sup>M</sup>	<b>0.003</b> (0.35)	0.998 (<0.01)	0.411 (0.04)
Relative peak power (W·kg <sup>-1</sup> )	49.3 ± 6.9	52.5 (11.6)‡	0.70 <sup>M</sup>	44.5 ± 5.6	46.4 ± 4.2	0.58 <sup>S</sup>	<b>0.004</b> (0.35)	0.609 (0.01)	0.164 (0.12)
RSI (FT/CT)	1.36 (0.45)	1.35 ± 0.28	0.25 <sup>S</sup>	1.32 ± 0.17	1.07 (0.22)‡	0.63 <sup>M</sup>	<b>0.042</b> (0.20)	0.369 (0.04)	0.850 (<0.01)
mRSI (JH/CT)	0.83 (0.33)	0.88 ± 0.19	0.20 <sup>S</sup>	0.80 ± 0.15	0.72 ± 0.15	0.63 <sup>M</sup>	0.073 (0.15)	0.493 (0.02)	0.943 (<0.01)
mRSI (JH/TTO)	0.49 ± 0.12	0.50 ± 0.08	0.04 <sup>T</sup>	0.45 ± 0.08	0.42 ± 0.10	0.49 <sup>S</sup>	0.397 (0.03)	0.291 (0.05)	0.365 (0.04)
Net impulse (N·s)	157.4 ± 15.3	165.7 ± 14.3‡	0.84 <sup>M</sup>	151.1 ± 20.8	164.0 ± 24.3‡	0.76 <sup>M</sup>	<b>0.001</b> (0.42)	0.421 (0.03)	0.244 (0.07)
Unweighting duration (ms)	285.8 ± 51.3	325.6 ± 31.6‡	0.83 <sup>M</sup>	265.0 ± 26.6	342.6 ± 71.4‡	1.30 <sup>L</sup>	<0.001 (0.60)	0.087 (0.13)	0.515 (0.02)
Braking duration (ms)	155.9 ± 58.0	152.3 (84.3)	0.45 <sup>S</sup>	139.7 ± 14.2	183.4 ± 42.0‡	1.18 <sup>M</sup>	<b>0.001</b> (0.45)	0.114 (0.12)	0.729 (0.01)
Propulsion duration (ms)	221.5 ± 55.5	230.7 (38.0)	0.46 <sup>S</sup>	220.7 ± 23.3	258.0 ± 45.5‡	0.97 <sup>M</sup>	<b>0.002</b> (0.38)	0.316 (0.05)	0.601 (0.02)
Flight duration (ms)	508.6 ± 41.4	536.1 ± 33.6‡	1.02 <sup>M</sup>	483.2 ± 32.7	503.1 ± 39.1‡	0.86 <sup>M</sup>	<0.001 (0.53)	0.441 (0.03)	0.300 (0.06)
Take-off velocity (m·s <sup>-1</sup> )	2.47 ± 0.18	2.60 ± 0.16‡	1.43 <sup>L</sup>	2.30 ± 0.18	2.44 ± 0.17‡	1.22 <sup>L</sup>	<0.001 (0.68)	0.826 (<0.01)	0.809 (<0.01)
<b>Squat jump</b>									
Jump height (cm)	25.8 ± 4.4	29.0 ± 4.5‡	1.01 <sup>M</sup>	22.5 ± 4.2	27.1 ± 5.2‡	1.42 <sup>L</sup>	<0.001 (0.57)	0.327 (0.05)	0.597 (0.02)
Absolute PF (N)	1563.0 ± 249.0	1543.4 ± 244.1	3.64 <sup>L</sup>	1467.7 ± 286.1	1563.5 ± 264.5‡	0.62 <sup>M</sup>	0.221 (0.07)	0.070 (0.15)	0.318 (0.05)
Relative PF (N·kg <sup>-1</sup> )	24.1 ± 3.2	24.8 (1.9)	0.72 <sup>M</sup>	21.7 ± 2.4	23.5 ± 1.9‡	0.61 <sup>M</sup>	0.061 (0.17)	0.406 (0.04)	0.089 (0.15)
Absolute NPF (N)	889.6 ± 159.6	925.4 (234.8)	0.40 <sup>S</sup>	802.0 ± 200.5	898.4 ± 140.9	0.62 <sup>M</sup>	0.048 (0.18)	0.535 (0.02)	0.769 (0.01)
Relative NPF (N·kg <sup>-1</sup> )	14.3 ± 3.2	14.8 (1.8)	0.75 <sup>M</sup>	11.9 ± 2.3	13.8 ± 2.1‡	0.77 <sup>M</sup>	<b>0.030</b> (0.21)	0.396 (0.04)	0.085 (0.16)
Absolute peak power (W)	2847.3 ± 426.8	3054.2 ± 285.9‡	0.17 <sup>S</sup>	2676.5 ± 458.1	2932.0 ± 466.4‡	0.76 <sup>M</sup>	<0.001 (0.43)	0.682 (0.01)	0.347 (0.05)
Relative peak power (W·kg <sup>-1</sup> )	46.0 ± 6.1	48.3 ± 5.6‡	0.78 <sup>M</sup>	40.0 ± 6.2	43.7 ± 5.5‡	0.75 <sup>M</sup>	<b>0.001</b> (0.42)	0.388 (0.04)	0.512 (0.02)
Net impulse (N·s)	145.3 ± 23.7	165.4 ± 14.9‡	0.89 <sup>M</sup>	143.1 ± 21.8	162.2 ± 23.2‡	1.26 <sup>L</sup>	<0.001 (0.57)	0.889 (<0.01)	0.904 (<0.01)
Propulsion duration (ms)	276.9 ± 44.2	320.3 ± 41.9‡	0.24 <sup>S</sup>	313.0 ± 55.0	367.0 ± 47.5‡	0.81 <sup>M</sup>	<0.001 (0.49)	0.630 (0.01)	0.126 (0.12)
Flight duration (ms)	465.2 ± 38.5	498.0 ± 39.7‡	0.37 <sup>S</sup>	441.3 ± 37.5	482.0 ± 45.1‡	1.46 <sup>L</sup>	<0.001 (0.60)	0.549 (0.02)	0.727 (0.01)
Take-off velocity (m·s <sup>-1</sup> )	2.24 ± 0.20	2.38 ± 0.18‡	1.14 <sup>M</sup>	2.10 ± 0.19	2.30 ± 0.22‡	1.55 <sup>L</sup>	<0.001 (0.61)	0.298 (0.05)	0.611 (0.01)
<b>10/5 rebound jump</b>									
Average height top 5 (cm)	19.9 (13.9)	23.7 ± 6.6	0.43 <sup>S</sup>	21.8 ± 3.8	22.7 ± 4.4	0.45 <sup>S</sup>	0.056 (0.18)	0.037 (0.73)	0.925 (<0.01)
Average RSI top 5 (FT/CT)	2.27 (0.81)	2.18 ± 0.58	0.31 <sup>S</sup>	2.32 ± 0.45	2.43 ± 0.48	0.34 <sup>S</sup>	0.646 (0.01)	0.140 (0.11)	0.058 (0.20)
Peak RSI (FT/CT)	2.46 (1.10)	2.40 ± 0.70	0.24 <sup>S</sup>	2.54 ± 0.51	2.60 ± 0.48	0.18 <sup>T</sup>	0.661 (0.01)	0.308 (0.06)	0.184 (0.10)
Average mRSI top 5 (JH/CT)	1.04 (0.77)	1.21 ± 0.47	0.06 <sup>T</sup>	1.19 ± 0.24	1.23 ± 0.26	0.44 <sup>S</sup>	0.647 (0.01)	0.405 (0.04)	0.151 (0.12)
Peak mRSI (JH/CT)	1.23 (1.06)	1.31 ± 0.50	0.16 <sup>S</sup>	1.33 ± 0.29	1.40 ± 0.30	0.34 <sup>S</sup>	0.955 (<0.01)	0.294 (0.06)	0.126 (0.13)
Average GCT top 5 (s)	0.174 ± 0.02	0.180 (0.030)	0.51 <sup>S</sup>	0.185 ± 0.040	0.180 ± 0.040	0.15 <sup>T</sup>	0.129 (0.12)	0.072 (0.16)	0.911 (<0.01)
Average force top 5 (N)	2057.2 ± 242.6	1988.3 ± 336.5	0.19 <sup>S</sup>	2098.9 ± 339.8	2182.4 ± 218.7	0.28 <sup>S</sup>	0.912 (<0.01)	0.258 (0.06)	0.155 (0.11)

**Table 3**  
**Statistical analysis within- and between-groups for all dependent variables. (Continued)**

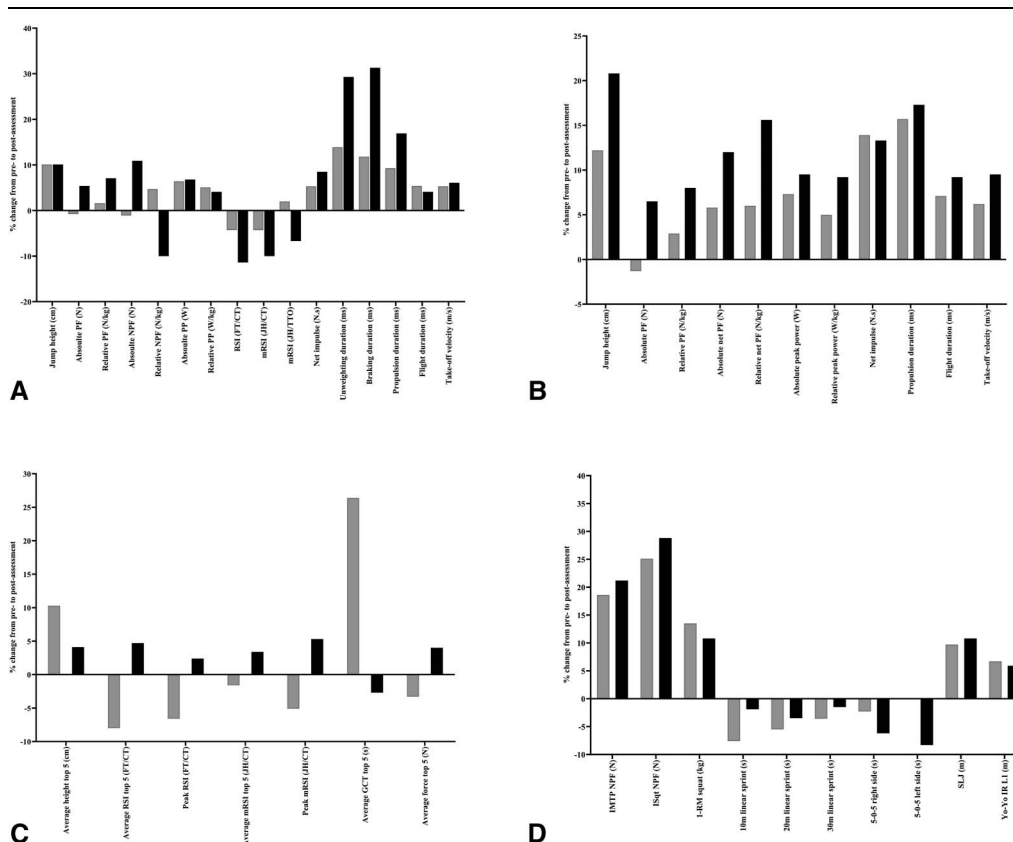
Variable	Complex ascending group			Complex descending group			Main effect time $p (\eta_p^2)$	Interaction effect time × group $p (\eta_p^2)$	ANCOVA $p (\eta_p^2)$
	Pretest†	Post-test†	Hedges $g$	Pretest†	Post-test†	Hedges $g$			
<b>Strength measures</b>									
IMTP NPF (N)	1236.8 ± 191.2	1466.5 ± 225.0‡	1.00 <sup>M</sup>	1210.9 ± 264.8	1467.6 ± 278.9‡	1.43 <sup>L</sup>	<0.001 (0.65)	0.745 (0.01)	0.297 (0.06)
ISqt NPF (N)	1667.7 (501.1)	2029.3 ± 445.8‡	1.59 <sup>L</sup>	1289.5 (606.4)	1864.0 ± 344.4‡	1.76 <sup>L</sup>	<0.001 (0.79)	0.921 (<0.01)	0.613 (0.02)
1RM squat (kg)	90.2 ± 10.2	102.4 ± 9.6‡	4.68 <sup>L</sup>	85.0 (20.0)	93.0 ± 11.8‡	2.68 <sup>L</sup>	<0.001 (0.94)	<b>0.017</b> (0.25)	0.111 (0.14)
<b>Linear sprint &amp; change of direction speed time</b>									
10-m linear sprint (s)	1.97 ± 0.14	1.82 ± 0.17‡	0.73 <sup>M</sup>	1.95 ± 0.17	1.91 ± 0.17	0.22 <sup>S</sup>	<b>0.028</b> (0.25)	0.165 (0.11)	0.176 (0.12)
20-m linear sprint (s)	3.38 ± 0.19	3.19 ± 0.22‡	1.05 <sup>M</sup>	3.38 ± 0.21	3.27 ± 0.29	0.43 <sup>S</sup>	<b>0.006</b> (0.36)	0.513 (0.03)	0.459 (0.04)
30-m linear sprint (s)	4.69 ± 0.25	4.53 ± 0.28‡	0.90 <sup>M</sup>	4.78 ± 0.30	4.70 ± 0.30	0.24 <sup>S</sup>	<b>0.039</b> (0.33)	0.394 (0.04)	0.392 (0.05)
5-0-5 right side (s)	2.98 ± 0.24	2.91 ± 0.23	0.44 <sup>S</sup>	3.00 ± 0.24	2.81 ± 0.21‡	1.03 <sup>M</sup>	<b>0.002</b> (0.43)	0.130 (0.13)	0.443 (0.04)
5-0-5 left side (s)	2.91 ± 0.19	2.91 ± 0.22	0.02 <sup>T</sup>	3.02 ± 0.30	2.77 ± 0.23‡	0.76 <sup>M</sup>	<b>0.042</b> (0.22)	0.038 (0.23)	0.303 (0.07)
<b>Other measures</b>									
SLJ (m)	2.37 ± 0.15	2.60 ± 0.22‡	1.16 <sup>M</sup>	2.22 ± 0.28	2.46 ± 0.29‡	2.084 <sup>L</sup>	<0.001 (0.73)	0.919 (<0.01)	0.876 (<0.01)
Yo-Yo IR L1 (m)	600 (160)	640 (160)‡	2.14 <sup>L</sup>	610.0 ± 173.2	645.8 ± 145.1‡	0.68 <sup>M</sup>	<0.001 (0.54)	0.653 (0.01)	0.705 (0.01)

\*1RM = 1 repetition maximum; CT = contact time; FT = flight time; GCT = ground contact time; IMTP = isometric midhigh pull; IR L1 = intermittent recovery level 1; ISqt = isometric squat; JH = jump height; mRSI = modified reactive strength index; NPF = net peak force; PF = peak force; RSI = reactive strength index; SLJ = standing long jump; TTO = time to take-off; L = large; M = moderate; S = small; T = trivial.

†Non-normally distributed data presented as median and interquartile range.

‡Significantly different from pretest using the paired *t* test with Bonferroni corrections.

§Significantly different from complex ascending group using Bonferroni-adjusted *t* test on adjusted mean with pretest values and resistance training experience as covariates.



**Figure 2.** Percentage change (relative) in dependent variables between pre- and postassessments for complex ascending (grey bars) and descending training (black bars) groups. (A) Countermovement variables, (B) squat jump variables, (C) rebound jump variables, and (D) remaining variables. 1RM = 1 repetition maximum; CT = contact time; FT = flight time; GCT = ground contact time; IMTP = isometric midhigh pull; IR L1 = intermittent recovery level 1; ISqt = isometric squat; JH = jump height; mRSI = modified reactive strength index; NPF = net peak force; PF = peak force; RSI = reactive strength index; SLJ = standing long jump; TTO = time to take-off.

The findings demonstrated that both sequencing methods produced similar improvements in CMJ and SJ height, and take-off velocity, net impulse, propulsion duration, flight time, and peak power. However, the mechanical strategies underpinning these improvements differed between groups. Indeed, take-off velocity is the primary determinant of vertical jump height and is most accurately derived using the impulse-momentum approach (51). Further, take-off velocity is determined by the net propulsive impulse relative to body mass (18). Therefore, increases in impulse magnitude and propulsion duration (propulsive impulse = force  $\times$  propulsion duration) provide a clear mechanistic explanation for the observed performance enhancements during vertical jumps (26). Despite similar within-group improvements in jump height, the CDT group demonstrated different adaptations in force-related variables in CMJ. For example, a significantly higher peak force during CMJ was observed after CDT compared with CAT. In addition, although a significant between-group difference was not observed, the CDT group showed a significant within-group increase in braking duration during CMJ, whereas the CAT group did not. The braking phase reflects eccentric deceleration of the center of mass and is indicative of force absorption capacity (27). Subsequently, prolonged braking duration may indicate enhanced eccentric strength, increased impulse accumulation, and a longer time to develop force because of slower SSC function (13,19). It could be plausible that performing RT exercise at the beginning of the session may have led to a residual fatigue effect on BT exercise during CDT, where the neuromuscular adaptations altered (11,35). Consequently, rather than enhancing SSC efficiency, subjects in the CDT group may have relied more on force production and impulse accumulation to achieve the observed improvements in jump performance.

Despite improvements in CMJ and SJ, RJ variables did not improve significantly in either group after the intervention. It suggests that the intervention favored longer force application strategies in CMJ and SJ, but it did not translate to improvements in the fast SSC task (i.e., during RJ). This finding contrasts with previous CT studies that reported improvements in RSI (23,39,52). The absence of significant changes in RSI in the present study may be explained by several factors. First, the subjects in the current study exhibited relatively high baseline RSI values (2.54–2.57), likely reflecting their training status and suggesting the presence of a ceiling effect or diminished training returns. In contrast, previous CT studies reporting RSI improvements typically involved subjects with substantially lower baseline RSI values (0.59–1.16), which increased to 0.74–1.55 after training, indicating a larger window for adaptation (23,39,52). These differences suggest that improvements in RSI may be more readily achieved in individuals with lower initial reactive strength or training experience (30). Second, the ballistic component of the present intervention was limited to pogo jumps as the sole exercise targeting fast SSC function. This may have been insufficient to elicit meaningful adaptations in muscle-tendon unit stiffness, which is a key determinant of fast SSC performance. Indeed, increased musculotendinous stiffness has been shown to enhance elastic energy storage and recoil, thereby optimizing force transmission during rapid ground contacts (15,25). In contrast, prior CT studies that observed RSI improvements implemented multiple ballistic exercises with progressively increasing intensity and complexity, thereby providing a more comprehensive stimulus for fast SSC adaptation (23,39,52). In addition, the relatively short duration of the present intervention (i.e., 6 weeks) may have limited the extent of adaptations in fast SSC characteristics.

Indeed, previous meta-analyses reported that jump training durations of more than 7 weeks are required to enhance lower-body stiffness (30) and RSI (32).

Moreover, both CAT and CDT produced large improvements in maximal dynamic and isometric strength, as evidenced by significant increases in IMTP net peak force (18.6–21.2%), ISqt net peak force (25.1–28.8%), and 1RM squat (10.8–13.5%). The evidence for CT intervention enhancing 1RM squats is well documented in the literature (4,46,47). Further, the findings are consistent with studies demonstrating improvement in IMTP measures after CT intervention (17,31,53). To the author's knowledge, this is the first study to examine the effect of CT on ISqt, thereby advancing the body of knowledge. In addition, although a significant time  $\times$  group interaction was observed for the 1RM squat, after accounting for pretest scores and differences in RT experience as covariates, the difference was not significant. This indicates that both sequencing formats are equally effective in improving dynamic and isometric strength in university athletes with varying resistance training experience. Of note, the subjects in the present study were relatively weak (relative 1RM squat; CAT = 1.4 kg $\cdot$ kg<sup>-1</sup>, CDT = 1.3 kg $\cdot$ kg<sup>-1</sup>). Literature suggests that relative strength plays a critical role in determining both performance and responsiveness to training interventions (41). Specifically, the authors proposed that individuals exist along a continuum of strength development (e.g., strength deficit, strength association, and strength reserve), where weaker or moderately trained individuals (placed in strength association phase [relative strength = 0.5–2.0]) typically demonstrate broader improvements across multiple physical qualities, whereas stronger individuals (relative strength >2.0) may exhibit more specific and diminished returns (41). Accordingly, the improvements observed across multiple performance measures in this study are consistent with the subjects' strength level (40,41). However, it is possible that stronger individuals may show different adaptations to CAT vs. CDT and, therefore, should be investigated in future studies.

Similarly, no significant interaction effects (or analyses with baseline as a covariate) were observed in linear sprints, CODS, and SLJ performance, indicating similar improvements across both groups and no effects of exercise order. Biomechanically similar RT and BT exercise pairings likely facilitated strength and power transfer to horizontal sprinting and jumping tasks (22,35). Improvements in sprint performance after CT may be attributed to enhanced rate of force development, increased motor unit recruitment, and improved inter- and intramuscular coordination, which collectively contribute to more effective force application during acceleration phases (4,44,45,47). In addition, the endurance performance increased after both interventions, despite the absence of endurance-specific training (although subjects were not restricted from regular sport-specific training), in line with a previous study on a CDT intervention (35). The observed improvements in Yo-Yo IRL1 performance after CT may be explained by enhanced musculotendinous stiffness (1), running economy (24), or metabolic adaptations (e.g., lactate dehydrogenase, Na<sup>+</sup>-K<sup>+</sup> pump expression, etc.) (50). Furthermore, an increase in muscular strength and power after CT might reduce the force required to maintain a given speed during intermittent aerobic tests (24). In addition, the aforementioned adaptations may reduce fatigue during aerobic tests, allowing athletes to run at higher speeds for longer periods (24). Moreover, concurrent sport-specific training may also have contributed to improvements in intermittent endurance capacity.

This study has a few limitations that should be acknowledged when interpreting the findings. First, although randomization was performed, differences in resistance training experience may have influenced the magnitude of training adaptations, despite statistical adjustment for resistance training experience as a covariate. Future studies may use stratified sampling to address this issue. Second, the sample size was relatively small and unequal because of dropouts. Although the sample size was estimated before the study, a larger sample size may be required to generalize the findings. Third, the absence of an active control group limits the ability to compare the findings with a controlled condition. Fourth, qualitative data, such as ratings of perceived exertion or questionnaires, would provide greater insights into the comparison of CAT and CDT. Fifth, the study was limited to a 6-week period; a longer study may yield different findings. Sixth, wrist straps were not used during the IMTP assessment. Straps have been shown to influence the force produced during the IMTP (8). Although a consistent testing approach (i.e., without strap use) was used in the current study, future research should incorporate straps to establish whether this affects the results. Finally, the study included only university-level male athletes, which may limit the generalizability of the findings to other populations (e.g., elite, untrained, female).

### Practical Applications

In line with previous literature, CT as a whole appears to be effective in improving vertical and horizontal jumps, linear sprints, CODS, maximal dynamic and isometric strength, and intermittent endurance. In addition, the sequencing order of RT and BT exercises does not affect most of the adaptations when volume and intensity are matched. Only the CMJ absolute peak force was higher after the CDT compared with the CAT. Therefore, practitioners may use either CT format to improve neuromuscular performance in male university-level athletes. However, practitioners may prefer adopting a CDT approach, in which RT exercises performed at the beginning of the session may lead to residual fatigue, thereby requiring increased peak force production during CMJs performed later in the session, which may induce specific neuromuscular adaptations relating to peak force generation during CMJ.

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informed about the purpose, content, and potential benefits and risks associated with the study, and they signed the informed consent forms.

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