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Does complex contrast training induce higher physical fitness improvement in stronger compared to weaker individuals?

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Abstract

This study compared the effects of complex contrast training (CCT) on measures of physical fitness in stronger compared to weaker individuals. Forty-one participants were initially recruited for relative strength assessment in the back squat. Thereafter, 26 participants were purposively assigned to either a stronger group (CCT-ST; relative strength ≥1.75; n = 12) or a weaker group (CCT-WK; relative strength <1.55; n = 14). Physical fitness tests were assessed pre- and post-six weeks of CCT training. Tests included 30-m sprint for speed, standing long jump and countermovement jump for power, and isokinetic peak torque of the knee flexors and extensors for strength. ANOVA revealed a significant effect of time for all dependent variables (all p <0.001, ηp2 = 0.83 – 0.89 [large]). Post-hoc tests indicated significant performance improvements within-group for CCT-ST (all p <0.001, Hedge's g = 0.27 – 0.98 [small to moderate], %Δ = 3.0 – 16.4) and CCT-WK (all p <0.001, Hedge's g = 0.37 to 1.34 [small to large], %Δ = 3.1 – 17.4) for all dependent variables. No group-by-time interaction was found for the included variables. In conclusion, CCT intervention provided similar effects on the assessed measures of physical fitness in both stronger as well as weaker active individuals. Therefore, CCT can be an effective training strategy to improve physical fitness among active individuals irrespective of their relative strength.

Keywords: *Plyometric exercise, human physical conditioning, resistance training, muscle strength, exercise, athletic performance*

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INDIVIDUAL RESPONSE TO COMPLEX CONTRAST TRAINING
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Introduction

Complex training is a method to improve physical fitness attributes such as speed, explosive strength, maximal strength among various population groups (e.g., soccer, active adults) (Sáez de Villarreal et al., 2013; Thapa et al., 2021; Thapa et al., 2022). This training method utilizes both high-load low-velocity activity (e.g., heavy resistance exercises) (Spineti et al., 2016) and low-load high-velocity activity (e.g., plyometric exercises) (Ramirez-Campillo et al., 2022; Thapa, Kumar, & Sharma, 2020) in the same session, and specifically targets

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both the force as well as the velocity component within the force-velocity spectrum (Cormier et al., 2022). Indeed, there are four possible sequencing of the aforementioned high-load and low-load activities within a single session and recently Cormier et al. (2022) have clarified the terminology used to describe each combination. For example, when a high-load exercise is performed first and subsequently followed by a low-load exercise in a set-by-set fashion, it is termed complex contrast training (CCT). Other combinations include the high-load exercise sets to be completed first followed by the low-load exercise sets (i.e., complex descending training) and vice-versa (i.e., complex ascending training) or French contrast training which is a subset of CCT (Cormier et al., 2022).

Among the aforementioned exercise sequencing combinations, CCT is suggested to benefit by the means of two different mechanisms. Firstly, the optimization of the force-velocity spectrum using high-load (low velocity) and low-load (high velocity) exercises, and secondly, the post-activation performance enhancement (PAPE) (Blazevich & Babault, 2019), which improves the performance of low-load activity due to the potentiating effect of the heavy-load activity (Thapa, Kumar, Kumar, et al., 2020), thereby enhancing the CCT outcomes. The PAPE is additionally associated with increased muscle temperature, muscle/cellular water content, alteration in the motor pattern, or post-activation potentiation (Blazevich & Babault, 2019). The post-activation potentiation is the enhancement in the muscle force (up to ~28 seconds) due to phosphorylation of the myosin light chain in type II fibers. It is suggested that the high-load activity stimulates the Ca2+ into the myoplasm, activating the myosin light chain kinase which phosphorylates the light chains, thereby promoting the actin-myosin cross-bridges (Blazevich & Babault, 2019; Cormier et al., 2022; Sale, 2002).

Furthermore, Cormier et al. (2020) reported the CCT to be more effective in improving maximal strength, vertical jump, and sprinting ability compared to complex descending training, suggesting that the PAPE promotes added neuromuscular adaptations through CCT compared to another complex training sequencing (i.e., complex descending training). Indeed, the most important training considerations for CCT (Cormier et al., 2022) are often based on acute studies conducted on PAPE. For example, the long-term adaptations to CCT intervention on stronger versus weaker individuals (i.e., based on their initial strength) are often speculated with findings obtained from PAPE-based acute studies (Carter & Greenwood, 2014; Cormier et al., 2022). Although these speculations are based on sound rationale on how stronger individuals exhibit greater potentiation compared to weaker individuals (Seitz et al., 2014; Suchomel et al., 2016), intervention-based CCT studies are warranted to confirm whether such mechanisms affect long-term adaptations.

Moreover, a previous study by Cormie et al. (2010) reported no influence of baseline relative strength level on the magnitude of performance improvement after ballistic power training. For example, similar improvement was observed in stronger versus weaker individuals for 30 m linear sprint time (effect size 0.65 versus 0.76) (Cormie et al., 2010). Although, whether such findings observed with ballistic power training will apply to CCT intervention needs further confirmation. Therefore, this study aimed to compare the effects of CCT intervention on 30 m linear sprint, standing long jump (SLJ), countermovement jump with arm swing (CMJA) height, and peak torque of both legs during unilateral isokinetic tests (i.e., leg extension and flexion) of stronger compared to weaker individuals. Based on the available literature (Seitz et al., 2014; Suchomel et al., 2016), we hypothesized significant improvement in the dependent variables in the stronger compared to the weaker group.

Methods

Participants

The required sample size to conduct the study was estimated using statistical software (G*power; University 130 of Düsseldorf, Düsseldorf, Germany). The following variables were included in the a priori power analysis: study design, two groups; two measurements; alpha error <0.05; nonsphericity correction =1; correlation between repeated measures = 0.5; desired power (1-ß error) = 0.80; effect size (f) of 0.33 based on a previous study that investigated the effects of relative strength (i.e., stronger versus weaker individuals) after power training on 30 m linear sprint performance (Cormie et al., 2010).

The results of the a priori power analysis indicated that a minimum of 11 participants would be needed for each group to achieve statistical significance for 30 m linear sprint performance. Thereafter, 41 male participants were initially recruited for relative strength assessments in the back squat. Based on a previous study (Seitz & Haff, 2016), a total of 26 participants were finally selected who were grouped into stronger (i.e., relative strength ≥1.75; n = 12) or weaker individuals (i.e., relative strength <1.55; n = 14). Fifteen participants were excluded with a relative strength of <1.75 to ≥1.55 in order to establish two distinct experimental groups. Eligibility criteria for this study required participants to be university students who were actively participating in the conditioning program offered as a part of the course curriculum for a minimum duration of five hrs per week, had a minimum of one year of resistance training experience, and were free from lower limb injuries six months before the study. The demographics of the participants are presented in Table 1. The potential risks and benefits of this study were explained to the participants before the study. Thereafter, informed consent forms were signed by participants. The local ethical committee of Rashtriya Raksha University approved this study.

Table 1. Participant demographics for stronger and weaker groups.

	CCT-Stronger	CCT-Weaker	p-value
Age (yrs)	20.7 ± 2.0	21.0 ± 1.88	0.667
Height (cm)	170.8 ± 7.4	177.5 ±7.7	0.032
Body Mass (kg)	61.9±6.4	68.0±7.0	0.031
1RM squat (kg)	112.9 ± 11.3	95.4±7.5	<0.001
Relative strength (kg/kg)	1.8 ± 0.1	1.4±0.1	<0.001

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Procedure

Before the start of the intervention, familiarization sessions were conducted for the CCT exercises and testing procedures to reduce the learning effects. Demographic data were collected and one-repetition maximum (1RM) tests for back squats were performed during familiarization sessions. Thereafter, the participants were grouped based on their relative strength (i.e., 1RM/body mass) into two experimental groups, i.e., stronger individuals (CCT-ST; relative strength of 1.75 or more) and weaker individuals (CCT-WK; relative strength less than 1.55). A schematic representation of the study design is in Figure 1. Participants were asked to refrain from any strenuous activity for 24 hrs and were asked to eat a habitual meal and refrain from consuming caffeine for three hrs before testing. A two (within-subject; pre-post) by two (between-subject; CCT-ST, CCT-WK) experimental design with the baseline scores as a covariate was used to compare the effects of training intervention on 30 m linear sprint, SLJ, CMJ, and peak torque of both legs during unilateral isokinetic tests (i.e., leg extension and flexion). Pre-post measurements were performed at similar times during the day for all participants to minimize circadian effects, with 30 m linear sprint, SLJ, and CMJ conducted on day one and isokinetic testing conducted on day two. The sequence of testing order was the same for all the participants. Upon arrival for testing, participants underwent a 10-min general warm-up procedure.

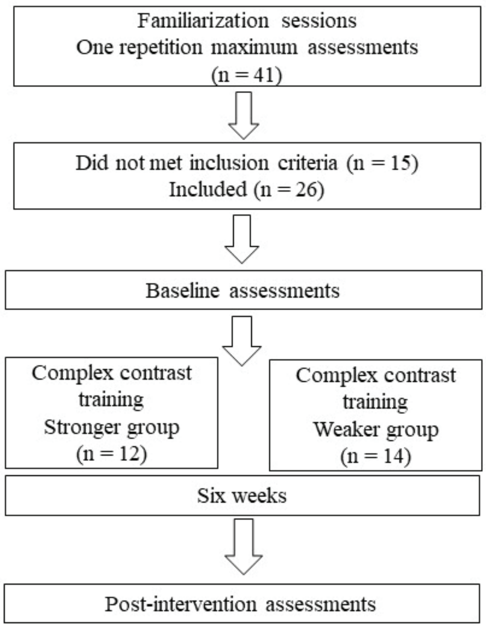

Figure 1. Schematic representation of the study

Training intervention

Before the start of the training intervention, 1RM assessments were conducted according to methods outlined by Faude et al. (2013) to define the intensity of each participant for bench press, barbell lunges, Romanian deadlift, and squat. Before each assessment a 10-min general warm-up was conducted, including, jogging, dynamic stretching, and body weight exercise (e.g., freehand squat, walking lunges, push-ups). A short specific warm-up consisting of five to ten repetitions with a load of 40 – 60% as well as three to five repetitions with about 60 – 80% of the estimated 1RM was performed. Thereafter, the load was

Table 2. Protocols for complex contrast training intervention.

	High-load resistance activity		Low-load high-velocity activity	
	Exercise	Sets × reps	Exercise	Sets × reps
Week 1-2	Squat	3 × 15	Squat jump	3 × 6
65 % 1RM	Romanian deadlift	3 × 15	Kettlebell swing	3 × 10
	Barbell lunge	3 × 15	Barbell high knees	3 × 15 sec
	Bench press	3 × 15	Plyo-push up	3 × 6
Week 3-4	Squat	3 × 10	Squat jump	3 × 8
75% 1RM	Romanian deadlift	3 × 10	Kettlebell swing	3 × 10
	Barbell lunge	3 × 10	Barbell high knees	3 × 20 sec
	Bench press	3 × 10	Plyo-push up	3 × 8
Week 5-6	Squat	3 × 6	Squat jump	3 × 10
85% 1RM	Romanian deadlift	3 × 6	Kettlebell swing	3 × 10
	Barbell lunge	3 × 6	Barbell high knees	3 × 25 sec
	Bench press	3 × 6	Plyo-push up	3 × 10

gradually increased in steps of 10 kg or less to achieve the 1RM within a maximum of five sets. The rest between 1RM attempts was four mins.

The training intervention was conducted for a period of six-week duration. The participants in both CCT-ST and CCT-WK had similar activity levels during the intervention period. The exercises used in the contrast pairs for CCT were squat with CMJ, lunges with barbell high knees, Romanian deadlift with kettlebell swings, and bench press with plyometric push-ups (Kumar et al., 2023). Biomechanically similar exercises were selected for pairing as per recommendations from Cormier et al. (2022). More details on the training protocol used across the six-week intervention are presented in Table 2.

Assessments

30-m Linear sprint test

The protocol was adapted from the methods outlined in a previous study (Singh, Kushwah, Singh, Thapa, et al., 2022) and conducted on an outdoor synthetic track. Participants were instructed to stand behind a start line with a self-selected leg forward and start only after the command of the assessor. Two independent assistants who were not part of this study were recruited as timekeepers (between timekeepers interclass correlation coefficients [ICC] were 0.99) and assigned to record the timing of each trial using a hand stopwatch (Casio S053 HF-70W-1DF, Casio Computer Co., Ltd., Tokyo, Japan). The times recorded by the two timekeepers were averaged for analysis. Three trials were conducted with a one-min recovery between trials, and the fastest trial was selected for further analysis. The ICC for test-retest was 0.86 (95% confidence interval [CI]: 0.61 – 0.95).

Standing long jump

The protocol was adapted from methods outlined in a previous study (Singh, Kushwah, Singh, Ramirez-Campillo, et al., 2022) and conducted on a synthetic outdoor track. Participants stood behind a marked start line with feet slightly apart and were instructed to swing their arms and perform a countermovement to a self-selected depth before taking off and landing with both legs. Verbal encouragement was provided to jump as far as possible. The measurement was recorded from the start line to the nearest point of contact on the landing (i.e., the back of the nearest heel). Three jumps were performed with one-min rest between jumps, and the longest jump was selected for analysis. The ICC for test-retest was 0.93 (95% CI: 0.81 – 0.98).

Countermovement jump with arm swing

An inertial moment sensor (BTS G-walk, Italy) was used to measure the vertical jump height during CMJ. A pilot study reported the sensor to be valid and reliable (concurrent to MyJump 2 [ICC = 0.96, r = 0.973, mean difference = 0.2 ± 1.3, and t-test p = 0.550]) for measuring the CMJ performance. The sensor was placed on the lower back using a belt with the center of the device at the fifth lumbar vertebrae. Participants stood with feet slightly apart and were instructed to swing their arms and perform a countermovement to a self-selected depth before taking off and landing with both legs. Knee flexion was not permitted during the flight phase of the jump. Three trials were performed with one-min rest between jumps, and the best trial was selected for analysis. The ICC for test-retest was 0.96 (95% CI: 0.89 – 0.99).

Isokinetic tests

The tests were conducted on a HUMAC NORM isokinetic dynamometer (Computer Sports Medicine Inc., Stoughton, USA). A general 10-min warm-up was completed before the test which included jogging and dynamic stretching of the lower limbs. Thereafter participants sat on the machine's chair, with the axis of rotation of the dynamometer arm aligned with the axis of rotation of the knee. The 'Knee Extension/Flexion' test was selected to be performed with isokinetic 'CONC/CONC' mode. The right side was always selected first across all testing sessions. The test protocol included a set of six repetitions at 60°/seconds speed with one-min of rest between sets. Verbal instructions were provided to push and pull as hard and fast as possible throughout the full range of motion. Furthermore, the screen was positioned so participants could see real-time feedback on their effort. Two sets were performed and the highest peak torque (PT) value obtained was selected for analysis. The ICC for test-retest was 0.99 (95% CI: 0.98 – 1.00) for right knee extension, 0.97 (95% CI: 0.94 – 0.99) for right knee flexion, 0.93 (95% CI: 0.84 – 0.99) for left knee extension, and 0.98 (95% CI: 0.97 – 0.99) for left knee flexion.

Statistical analysis

The analyses were conducted using IBM SPSS version 20.0.0 (IBM, New York, USA). The normality of data was verified using the Shapiro-Wilk test. Data are presented as means and standard deviations. A two (pre-post intervention) by two (CCT-ST, CCT-WK) mixed ANOVA with the baseline scores as a covariate was used to analyze the exercise-specific effects. Percentage change scores were also calculated for each variable in each group using the equation in Microsoft Excel ([meanpost – meanpre] / meanpre) × 100. Effects sizes (ES) in the form of partial eta squared (ɳp2) were used from ANOVA output. Hedge's g effect size derived from mean and standard deviations of pre- and post-measurements were calculated to assess within-group changes for each group. The magnitude of effects for ɳp2 was interpreted as small (<0.06), moderate (≥0.06-0.13), and large (≥0.14) (Cohen, 1988), while Hedge's g was interpreted as trivial (<0.2), small (0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0), very large (>2.0-4.0) and extremely large (>4.0) (Hopkins et al., 2009). The ICC between trials and assessors was interpreted as poor (<0.5), moderate (0.5-0.75), good (0.75-0.9), and excellent (>0.9) reliability based on the lower bound of the 95% confidence interval (CI; ICC95%CI lower bound) (Koo & Li, 2016). Statistical significance was set at p ≤ 0.05.

Results

No participants dropped out of the study, sustained any injuries, or missed any training sessions. The results for all dependent variables of the main analysis are presented in Table 3, with a graphical representation of pre-post percentage change in Figure 2. Individual response to CCT is represented in Figure 3, Figure 4 and Figure 5, respectively.

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Table 3. Statistical comparisons between complex contrast training (CCT) stronger versus weaker group.

	CCT-stronger (n =12)			CCT-weaker (n =14)			Time	Time × Group	ANCOVA
	Pre-test	Post-test	p-value [g] Magnitude	Pre-test	Post-test	p-value [g] Magnitude	p-value [ηp²] Magnitude	p-value [ηp²] Magnitude	p-value
	Mean ± SD			Mean ± SD					
30 m sprint (s)	4.61 ± 0.20	4.47 ± 0.18	<0.001 [0.71] Moderate	4.79 ± 0.18	4.64 ± 0.18	<0.001 [0.81] Moderate	<0.001 [0.83] Large	0.523 [0.02] Small	0.988
Standing long jump (m)	2.38 ±0.16	2.54±0.18	<0.001 [0.91] Moderate	2.37±0.15	2.51±0.15	<0.001 [0.91] Moderate	<0.001 [0.86] Large	0.330 [0.04] Small	0.340
Countermovement jump (cm)	38.82±5.29	45.18±7.10	<0.001 [0.98] Moderate	40.21±5.08	47.21±5.04	<0.001 [1.34] Large	<0.001 [0.87] Large	0.542 [0.02] Small	0.599
PT leg extension (right) (Nm)	166.0 ± 47.3	180.8±49.6	<0.001 [0.29] Small	166.4±37.7	180.5±36.7	<0.001 [0.37] Small	<0.001 [0.85] Large	0.805 [0.00] Small	0.809
PT leg extension (left) (Nm)	176.7±51.8	191.6±54.0	<0.001 [0.27] Small	159.1±30.5	171.6±29.6	<0.001 [0.40] Small	<0.001 [0.89] Large	0.223 [0.06] Moderate	0.294
PT leg flexion (right) (Nm)	112.4±21.6	122.3±24.9	<0.001 [0.41] Small	104.6±21.7	113.6±21.9	<0.001 [0.40] Small	<0.001 [0.85] Large	0.543 [0.02] Small	0.747
PT leg flexion (left) (Nm)	113.7±25.0	123.8±27.6	<0.001 [0.37] Small	99.4±20.4	107.6±20.6	<0.001 [0.39] Small	<0.001 [0.86] Large	0.450 [0.025] Small	0.450

Note: g – Hedges' g; Nm – Newton meters; PT – peak torque; ηp^2 – partial eta squared ; SD - standard deviation; ANCOVA - analysis of covariance

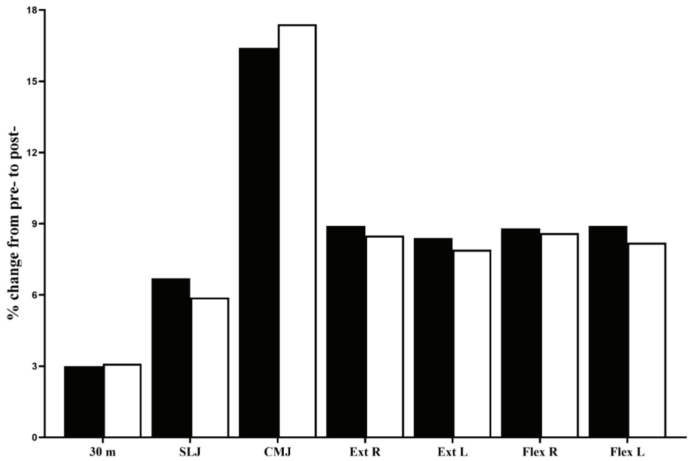

Figure 2. Relative (%) change in dependent variables between pre- and post-training intervention for the complex contrast training stronger group (CCT-ST; black bars) versus weaker group (CCT-WK; white bars). For all parameters, a significant effect of time was noted. No group-by-time interaction effects were noted. Hedge's g ranged from 0.27 to 0.98 for CCT-ST and from 0.37 to 1.34 for CCT-WK.

Note: 30 m (linear sprint time), CMJ (countermovement jump height), Ext (maximal knee extension isokinetic torque), Flex (maximal knee flexion isokinetic torque), L (left), R (right), SLJ (standing long jump distance).

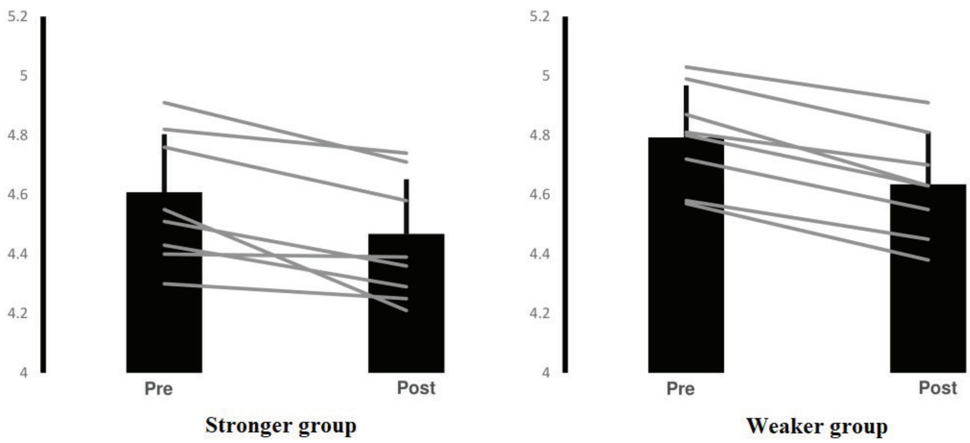

Figure 3. Mean (column) ± standard deviation (error bar) along with individual responses (grey lines) for 30-m linear sprint time prior to and following a six weeks CCT intervention between stronger and weaker groups

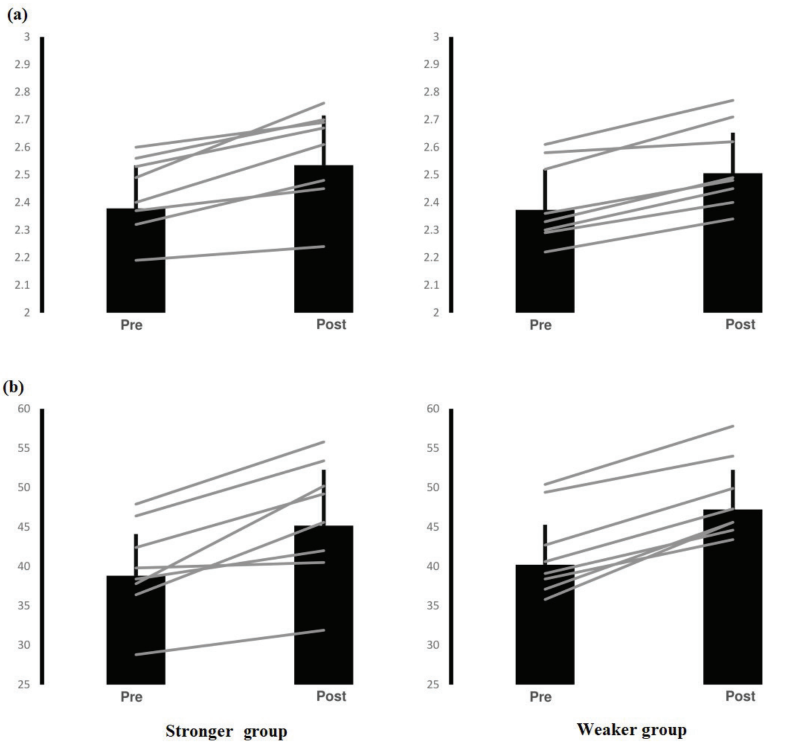

Figure 4. Mean (column) ± standard deviation (error bar) along with individual responses (grey lines) for (a) standing long jump distance and (b) countermovement jump height prior to and following a six weeks CCT intervention between stronger and weaker groups.

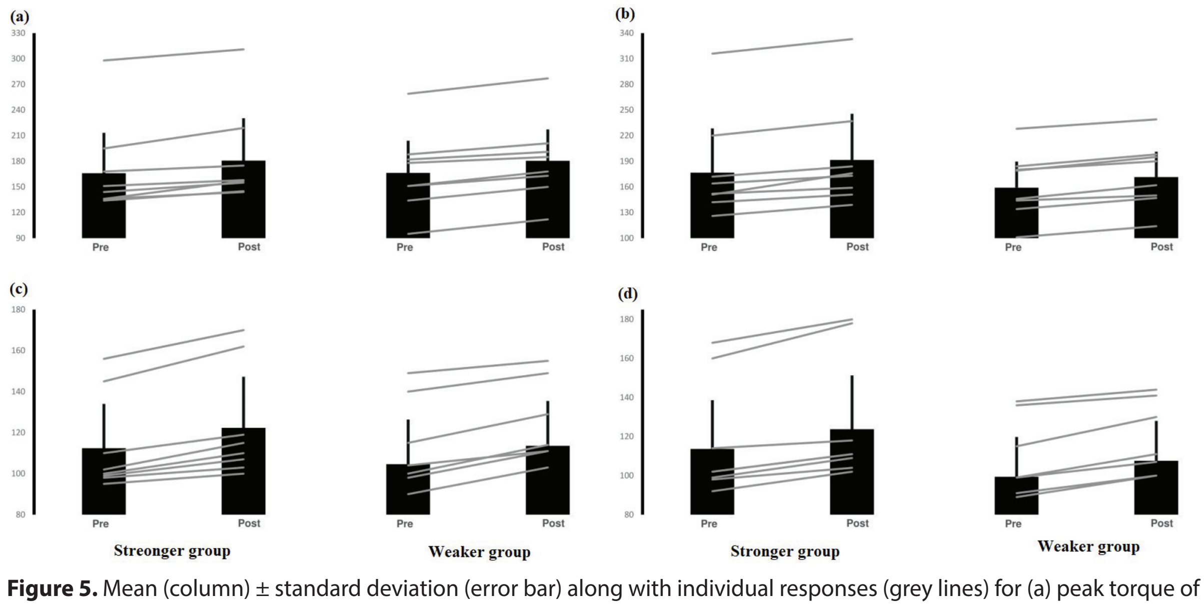

Figure 5. Mean (column) ± standard deviation (error bar) along with individual responses (grey lines) for (a) peak torque of right leg during extension, (b) peak torque of left leg during extension, (c) peak torque of right leg during flexion, and (d) peak torque of left leg during flexion prior to and following a six weeks CCT intervention between stronger and weaker groups.

There was a significant main effect of time with CCT intervention in all dependent variables (all $p < 0.001$; $\eta p2$ = 0.83 – 0.89 [all large]). However, no significant time × group interaction effects was observed for the dependent variables (p = 0.223 – 0.805; $\eta p2$ = 0.00 – 0.06 [small to moderate]). Furthermore, post-hoc tests using Bonferroni adjusted paired t-test revealed significant improvements in all dependent variables in CCT-ST (all $p < 0.001$, g = 0.27 – 0.98 [small to moderate], %Δ = 3.0 – 16.4) and CCT-WK (all $p < 0.001$, g = 0.37 – 1.34 [small to large], %Δ = 3.1 – 17.4). In addition, post-hoc tests with baseline scores as covariates showed no differences between CCT-ST and CCT-WK (p = 0.294 – 0.988).

Discussion

The study reported improvement in both stronger and weaker individuals after a six-weeks CCT intervention. The magnitude of improvement in CCT-ST was small for isokinetic leg strength and moderate for 30 m sprint time, SLJ distance, and CMJ height. While the magnitude of improvement in

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CCT-WK was small for isokinetic leg strength, moderate for 30 m sprint time and SLJ distance, and large for CMJ height. However, no significant differences were found in improvement with CCT between stronger or weaker individuals.

The improvement in both CCT intervention groups may be attributed to specific neuromuscular adaptations that may have led to an improved stretch-shortening cycle, increased motor unit recruitment, firing frequency, intra-and-inter-muscular coordination, and morphological changes that help with muscle's force-generating capacity (Cormier et al., 2022; Thapa et al., 2021; Thapa et al., 2022). Furthermore, incorporating high-load low-velocity and low-load high-velocity exercises during CCT may induce specific neuromuscular adaptations that optimize the force-velocity relationship (Cormier et al., 2022; Thapa et al., 2021; Thapa et al., 2022). Although the heavy resistance and plyometric exercises involves both the force and velocity components, it is possible to majorly target only one component (i.e., force or velocity) of the force-velocity spectrum (Cormier et al., 2022). This implicates that the heavy resistance exercises (greater force component) and plyometric exercises (greater velocity component) are placed at the opposite end of the force-velocity curve. However, including both resistance as well as plyometric exercise within a single training session as in the CCT format, may allow improvements across the spectrum (Cormier et al., 2022). In addition, optimization of the force-velocity relationship also helps recruit fast-twitch muscle fibers that underpin athletic performance (e.g., sprints, jumps) (Jiménez-Reyes et al., 2022; Macaluso et al., 2012).

Of note, previous studies have also reported hormonal adaptations such as increased testosterone level concentration in male soccer athletes following a six-week CCT intervention (Ali et al., 2019). Similarly, another six-week CCT study reported an increase in leg volume in junior male soccer players (Hammami et al., 2017). These hormonal and structural adaptations might be responsible for the strength-power development reflected through increased peak torque during the isokinetic assessments in our current study. In addition to the aforementioned rationale, another possible mechanism that may have contributed to the positive improvements in both CCT groups is the post-activation potentiation of performance (Blazevich & Babault, 2019). This phenomenon is suggested to work on the potentiating effects that higher-load activity may generate on the immediate performance of a lower-load activity (Blazevich & Babault, 2019). Indeed, Cormier et al. (2020) have reported that using high-load resistance exercises and low-load plyometric exercises in the CCT format is superior to performing the combination of the exercises in other formats (e.g., heavy resistance exercises completed first followed by plyometric exercises sets) in improving sprints, jumps, change of direction, and maximal strength.

Furthermore, our study reported that the initial relative strength level did not influence the improvement gains after six weeks of CCT. Previous studies have reported similar findings with ballistic power training (Cormie et al., 2010) and traditional resistance training protocol (Mangine et al., 2018). Cormie et al. (2010) compared the magnitude of performance improvement between strong and weak individuals after 10 weeks of a ballistic power training program. Both experimental groups reported significant improvements in jump and sprint performance after 10 weeks of training with no significant differences between strong and weak individuals. Similarly, Mangine et al. (2018) reported no differences in 1RM back squat, muscle size of rectus femoris, and vastus lateralis between strong and weak athletes after eight weeks of resistance training. One possible moderating factor that may have elucidated such findings is the principle of diminishing returns which suggests initial improvements are easily invoked and further improvements are harder to achieve. According to the aforementioned principle, the training program for individuals with greater strength levels needs to contain variability compared to weaker individuals to observe further enhancement (Newton & Kraemer, 1994). However, in our study both stronger and weaker individuals underwent similar training programs (i.e., frequency, intensity, time, type) during the six weeks. Although the training program was designed to target specificity to common athletic movements, the training may have lacked variability for the stronger individuals to observe greater improvement. Indeed, although non-significant (between groups), one finding reported in our study was higher magnitude improvement observed in CMJ performance for CCT-WK compared to CCT-ST (Hedge's g 1.34 versus 0.98). This difference in the magnitude of improvement for CMJ, favoring the weaker individuals may be in line with the principle of diminishing returns as priorly mentioned, where the weaker individuals had a greater window of oppurtunity for improvement (Sale, 1987). In line with this, the CCT has also been reported to increase the maximal squat strength among male soccer athletes (Thapa et al., 2022), that has shown to be strongly correlated with the vertical jump performance (Wisløff et al., 2004). Therefore, a speculative argument could be that the CCT-WK also improved the maximal strength to a greater extent compared to the CCT-ST, considering the greater window of oppurtunity and principle of diminishing returns (Newton & Kraemer, 1994; Sale, 1987) and thus a greater magnitude improvement in the CMJ.

There are limitations of this study that should be acknowledged. Firstly, our study included only active male participants, therefore the findings should not be extrapolated to females or athletes. Secondly, the training intervention was limited to a six-week duration. An investigation of longer duration may provide further information as to how stronger and weaker individuals adapt to CCT. Thirdly, this study included a small sample size. Although we conducted a sample size estimation before conducting the study, larger sample size may be required to support current findings. Fourthly, the absence of biochemical or physiological data collection. Such data would provide a better interpretation of the results.

Conclusion

Our findings suggest that there is no influence of initial strength level on improvement in physical fitness attributes after six weeks of CCT intervention. Therefore, CCT can be an effective training strategy to improve physical fitness among active individuals irrespective of their relative strength. However, the magnitude of improvements in stronger individuals was small for isokinetic leg strength and moderate for 30 m sprints, SLJ, and CMJ. Whereas the magnitude of improvements in weaker individuals was small for isokinetic leg strength, moderate for 30 m sprint and SLJ, and large for CMJ. Furthermore, future longitudinal studies (i.e., more than six-weeks duration) involving higher number of participants should examine if similar findings are observed in females as well as athletes participating in different sports. In addition, future studies may also examine how variability in the frequency, intensity, time, and type of exercises may affect the outcomes between stronger versus weaker individuals.

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Conflict of Interest

All authors declare no conflicts of interest regarding the content of this study.

Availability of data and material

All data generated or analyzed during this study will be/are included in the published article as Table(s) and Figure(s). Any other data requirement can be directed to the corresponding author upon reasonable request.

Author's contributions

RKT and GK conceived the idea and designed the study. GK was involved in data collection procedures. RKT performed the formal analysis and interpretation of the data. RKT and GK wrote or revise the draft of the manuscript. Both authors read and approved the final version of the manuscript.

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