sciendo

Original Paper

Biomedical Human Kinetics, 15, 201–210, 2023
DOI: 10.2478/bhk-2023-0024

Effects of complex-contrast training on physical fitness in male field hockey athletes

Rohit K. Thapa[1,2], Gopal Kumar[3], Anthony Weldon[4,5], Jason Moran[6], Helmi Chaabene[7,8], Rodrigo Ramirez-Campillo[9]

[1] Symbiosis School of Sports Sciences, Symbiosis International (Deemed University), 412115, Pune, India; [2] School of Physical Education and Sports, Rashtriya Raksha University, Gandhinagar, India; [3] Department of Exercise Physiology, Lakshmibai National Institute of Physical Education, Gwalior, India; [4] Centre for Life and Sport Sciences, Birmingham City University, Birmingham, UK; [5] Aston Villa Football Club, Birmingham, UK; [6] School of Sport, Rehabilitation and Exercise Sciences, University of Essex, Colchester, Essex, UK; [7] Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Potsdam, Germany; [8] High Institute of Sports and Physical Education of Kef, University of Jendouba, Tunisia; [9] Exercise and Rehabilitation Sciences Institute, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile

Abstract

Study aim: This study aimed to examine the effects of a six-week complex-contrast training (CCT) intervention on the physical fitness of male field hockey athletes.

Material and methods: Participants were randomized into a CCT (n = 8) or control (CG; n = 6) group. Physical fitness was assessed pre- and post-six-week intervention using a 30 m linear sprint test, medicine ball throw, standing long jump (SLJ), countermovement jump with arm swing (CMJA), modified T-test (MAT), and unilateral isokinetic maximal strength test (knee flexion and extension) of both legs. The six-week CCT intervention was integrated as three weekly sessions within the sport-specific training schedule of field hockey athletes. Each session included four contrast pair exercises (e.g., squat + squat jump). ANCOVA with baseline scores as a covariate was used to analyze the specific training effects.

Results: Significant differences between CCT and CG were observed in the 30 m sprint, CMJA, MAT, and isokinetic strength ($p < 0.001–0.013$) after the intervention, favoring the CCT group. Further, post-hoc analyses revealed significant pre to post improvements in all dependent variables for the CCT group ($p < 0.001–0.001$; effect size [g] = 0.28–2.65; %Δ = 3.1–16.3), but not in the CG ($p = 0.169–0.991$; g = 0.00–0.32; %Δ = 0.0–2.6).

Conclusion: Supplementing regular field hockey training with CCT is recommended as an effective training strategy to improve the performance of linear sprints, vertical jumps, changes of direction, and muscle strength in amateur male field hockey athletes.

Keywords: Plyometric exercise – Human physical conditioning – Resistance training – Muscle strength – Exercise – Athletic performance

Introduction

Field hockey is a high-intensity team sport characterized by bouts of intermittent activity that require players to perform repeated short sprints, tackles, ball strikes, accelerations, decelerations, and changes of direction during matches [14, 24]. Quantifying the workload of such activities during competitive field hockey matches also enables the differentiation of athletes' playing level. For example, international athletes performed 42% more high-speed running compared to national-level athletes [20]. Moreover, to improve performance in these activities athletes must be able to exert high forces at high velocities [10]. Therefore, appropriate training strategies, particularly those aimed at improving force – and power-generation capabilities, are required to improve key physical components of field hockey players [41].

To train the force and power capabilities of athletes, the combination of resistance and plyometric exercises

Author's address Rohit K. Thapa, Symbiosis School of Sports Sciences, Symbiosis International (Deemed University), 412115 Pune, Maharashtra, India rohit.thapa@ssss.edu.in

in a single session (i.e., complex training) may be a time-efficient strategy and can produce greater neuromuscular adaptions compared to a single training mode [12]. Indeed, a recent survey [42] reported that complex training was commonly employed by strength and conditioning coaches for prescribing resistance and plyometric exercises in professional soccer. To prescribe complex training there are four potential exercise sequences, 1) contrast training (CCT; resistance exercise followed by plyometric exercise in a set-by-set fashion (e.g., 85% one repetition maximum [1RM] squat immediately followed by a biomechanically similar low-load (high-velocity]), 2) ascending training (plyometric exercise sets completed before resistance exercise sets), 3) descending training (resistance exercise sets completed before plyometric exercise sets), and 4) French contrast (a subset of contrast training where heavy resistance exercise and plyometric exercise is performed first and then light to moderate resistance exercise and plyometric exercise is performed after) [12]. Of these, the more effective strategy for athletic development (e.g., sprinting, vertical jump, change of direction) in team sports seems to be CCT [13].

Furthermore, the use of exercises with contrasting loads in CCT promotes multi-modal adaptations throughout both ends of the force-velocity curve, required for the demands of field hockey [17]. This is achieved by including force (e.g., heavy resistance) and velocity (i.e., plyometric) dominant exercises within a single session. Furthermore, CCT may enhance the potentiation effect (e.g., increased motor unit recruitment) of performing a high load activity before a lower load one, generally termed post-activation performance enhancement (PAPE) [5, 29, 37]. Alternatively, one mechanism that may also be responsible for improvement through CCT is post-activation potentiation, which is defined as the enhancement in the muscle force (up to ~28 seconds) due to phosphorylation of the myosin light chain in type II fibers [5, 29, 30].

Aside from the aforementioned acute responses of CCT as a rationale, this training method is also effective in improving the physical fitness of athletes across different sports (e.g., soccer, handball, physically active adults) [8, 38, 39]. However, differences in physiological demands between field hockey to other team sports (e.g., soccer; handball) [36] preclude any confirmation of favorable effects from CCT to field hockey athletes. Indeed, there is limited and contrasting evidence regarding the effects of resistance training or plyometric training on the physical fitness of field hockey athletes [4]. For example, one study [28] reported that youth field hockey athletes (aged 12–14 years) improved their physical fitness (e.g., 10–30 m sprint time, CMJ height) following a six-week plyometric intervention compared to a control group. Similarly, another study [32] observed improvement in body composition, aerobic fitness, anaerobic fitness, strength, agility, and field hockey-specific performance after six-week of sprint-strength and agility training. In contrast to the aforementioned studies, an observational study reported a decreased 1RM squat (–14%) and bench press (–10%) among female field hockey athletes (aged ~20 years) from pre- to post-season [2]. The decrease in performance was observed even when athletes completed pre-season and in-season conditioning programs including speed, agility, and plyometric training two days per week, in addition to periodized upper-body and lower-body strength training three days per week [2].

Therefore, given the limited and contrasting evidence regarding the use of strength training (i.e., resistance or plyometric training) methods to improve the physical fitness of field hockey athletes, this study aims to compare the effects of a six-week CCT intervention on the physical fitness of field hockey athletes vs. a control group (CG, i.e., regular field hockey training similar to CCT group). Based on the available literature [12, 27, 39, 40], we hypothesized that CCT would result in significant improvements in physical fitness (i.e., 30 m linear sprint time, medicine ball throw [MBT] distance, standing long jump [SLJ] distance, countermovement jump with arm swing [CMJA] height, modified agility T-test [MAT]) time, and unilateral isokinetic maximal strength test (knee flexion and extension) of both legs compared to a control condition.

Materials and methods

This study was designed following the international guidelines for quality-based randomized controlled trials in the field [3, 26, 35].

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 for within-between interaction in repeated measures ANOVA: 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 0.73 based on a previous study that investigated the effects of six-week CCT in amateur soccer players (i.e., similar to field hockey) on linear sprint [7].

The results of the *a priori* power analysis indicated that a minimum of 4 participants would be needed for each group to achieve statistical significance for the main dependent variable of the study (i.e., linear sprint performance). Accordingly, 14 male participants were recruited for this study, with a slightly higher number of participants than recommended in case any participants dropped out. Eligibility criteria for this study required participants to

Table 1. Demographic characteristics of participants of the complex-contrast training (CCT) and control groups (CG)

	CCT (n = 8)	CG (n = 6)	*p*-value*
Age (yrs)	20.6 ± 1.5	21.7 ± 1.6	0.240
Height (cm)	171.3 ± 8.3	168.5 ± 4.7	0.482
Body mass (kg)	61.8 ± 7.9	65.0 ± 2.6	0.363
Field hockey training experience (years)#	2.3 ± 1.4	3.8 ±1.5	0.062

* – independent t-test between groups; # – field hockey training experience at university.

1) be competitive field hockey athletes who represented the university team at inter-university competitions, 2) be actively participating in field hockey for a minimum of five hours per week, 3) had a minimum of one year of resistance training experience, with correct technique to perform squats, deadlifts, lunges and bench press resistance training exercises, and 4) be free from lower limb injuries for at least six months before the study. Participants were randomly assigned (using randomization tool; www.randomizer.org) to CCT (n = 8) or a control group (CG; n = 6). A slightly higher number of participants were further assigned to the CCT group considering potential dropouts due to the intervention (e.g., not completing the assigned number of CCT sessions). Participants within each group possessed similar anthropometric characteristics (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 internal review board of Rashtriya Raksha University approved this study.

Procedures

Participants performed three familiarization sessions including CCT exercises and two familiarization sessions for the testing procedures undertaken one and two weeks before baseline testing, respectively. Demographic data were collected and 1RM tests were performed at least one week before baseline testing during familiarization sessions, including squat, barbell lunges, Romanian deadlift, and bench press, with results used for training prescription purposes (for more details, refer to the training intervention section of the manuscript). Participants were asked to refrain from any strenuous activity 24 hours before testing, to eat a habitual meal, and refrain from consuming caffeine three hours before testing. A two (within-subject; pre-post) by two (between-subjects; CCT, CG) randomized design was used to compare the effects of the CCT training intervention on linear sprint time, MBT distance, SLJ distance, CMJA height, MAT time, and unilateral isokinetic maximal strength test (knee flexion and extension) of both legs. Pre-post measurements were performed at similar times during the day for all participants to minimize circadian effects, with 30 m linear sprint time, MBT, SLJ, CMJA height, and MAT conducted on day one (6:00–8:00 AM), and isokinetic testing conducted on a separate day (24–72 h after day one) at 2:30–5:30 PM. The sequence of testing order was the same for all the participants. Upon arrival for testing, participants underwent a 10-minute general warm-up procedure. For the outdoor assessments during baseline and post-intervention assessments, the temperature, humidity, and wind velocity ranged from 28–31°C, 15–65%, and 0–10.8 km · h^{-1}, respectively. The CONSORT flow diagram is provided in Figure 1.

Load measurement for training prescription

Before the start of the training intervention, 1RM assessments were conducted according to the methods outlined in a previous study [15]. Before each assessment a 10-minute general warm-up was conducted, including jogging, dynamic stretching, and body mass-based exercises (e.g., freehand squat, walking lunges, push-ups). Afterward, a short specific warm-up consisting of five to 10 repetitions with a load of 40–60% as well as three to five repetitions at 60–80% of the estimated 1RM was performed. Thereafter, the load was gradually increased in steps of 10 kg or less to achieve the 1RM within a maximum of five attempts. The rest between 1RM attempts was four minutes. The 1RM obtained for squat, lunges, Romanian deadlift, and bench press were 94 ± 7 kg, 53 ± 6 kg, 78 ± 10 kg, and 66 ± 12 kg, respectively. No 1RM data was collected for the CG.

Training intervention

As per the recommendations of Cormier & colleagues [12] and based on a previous study [23], biomechanically similar exercises were selected for the contrast pairs used in the CCT: 1) squat with CMJ, 2) Romanian deadlift with kettlebell swing, 3) lunge with barbell high knees, and 4) bench press with plyometric push-up. The CMJ and plyometric push-ups were performed using the participant's body mass without external resistance, kettlebell swings with 10–20 kg, and barbell high knees with a 20 kg Olympic barbell. The participants were asked to perform both the high-load and low-load activities with the intention (i.e., effort) to attain maximal velocity in every repetition. The low-load activity was performed immediately

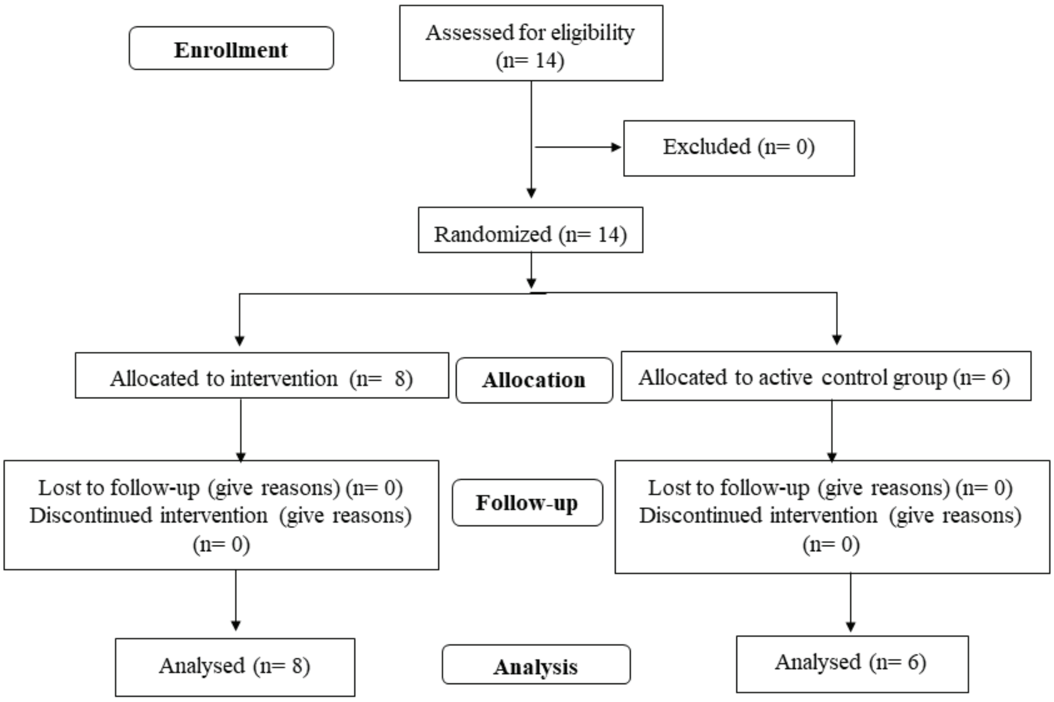

Figure 1. Schematic of the study design

Table 2. Protocol for complex-contrast training intervention

	High-load resistance activity		Low-load high-velocity activity	
	Exercise	Sets × reps	Exercise	Sets × reps
Weeks 1–2 65% 1RM	Squat	3 × 15	Squat jump	3 × 6
	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
Weeks 3–4 75% 1RM	Squat	3 × 10	Squat jump	3 × 8
	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
Weeks 5–6 85% 1RM	Squat	3 × 6	Squat jump	3 × 10
	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

1RM – one repetition maximum; reps – repetitions.

after (≤30 s) the high-load activity, with one-minute rest provided between consecutive sets, two minutes between contrast pairs (i.e., between squat with CMJ and Romanian deadlift with kettlebell swings), and ≥48 hours between sessions. Both the CCT group and CG were involved in regular field hockey training with morning sessions focused on strength and conditioning, and evening sessions focused on sport-specific technical-tactical aspects. The experimental group replaced three standard morning training sessions per week at the gym with CCT (for a total of 18 CCT sessions; Table 2), while the CG underwent regular conditioning sessions focused on the improvement of physical fitness (e.g., speed, agility, repeated sprint ability, aerobic endurance), and did not participate in any resistance or plyometric training sessions. The overall training volume during the six-week duration was similar between both groups.

Assessment protocols

30-m linear sprint test

Linear sprint protocols were adapted from methods outlined in a previous study [34] and conducted on an outdoor synthetic track. Participants were instructed to stand behind a marked 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) was 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 with a minimum work:rest ratio of 1:12 between trials, and the fastest trial was selected for analysis. The ICC for test-retest reliability was 0.80 (95% confidence interval [CI]: 0.87–0.96).

Medicine ball throw

Participants stood on the start line with feet shoulder-width apart. Thereafter, participants threw a 3 kg medicine ball backward overhead. The distance between the start line and the first contact of the ball was measured using a standard measuring tape. Two trials were conducted with a rest period of three-minute between trails, and the furthest throw was selected for analysis. The ICC for test-retest reliability was 0.88 (95% CI: 0.64–0.96).

Standing long jump

The protocol was adapted from methods outlined in a previous study [33] 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., back of the heels). Three jumps were performed with one-minute rest between jumps, and the longest jump was selected for analysis. The ICC for test-retest reliability was 0.96 (95% CI: 0.87–0.99).

Countermovement jump with arms swing

An inertial moment sensor (BTS G-walk, Italy) was used to measure the vertical jump height during CMJA. 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, t test $p = 0.550$]) to measure the CMJ height. 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-minute rest between jumps, and the highest trial was selected for analysis. The ICC for test-retest reliability was 0.87 (95% CI: 0.60–0.96).

Change of direction speed

The MAT was used to determine the speed with directional changes, including forward sprinting, left and right shuffling, and backward running. The protocol was adapted from methods outlined in a previous study (Figure 2) [31]. Two independent assistants who were not part of this study were recruited as timekeepers (between timekeepers ICC was 0.99) and assigned to record the timing of each trial using a hand stopwatch (Casio S053 HF-70W-1DF,

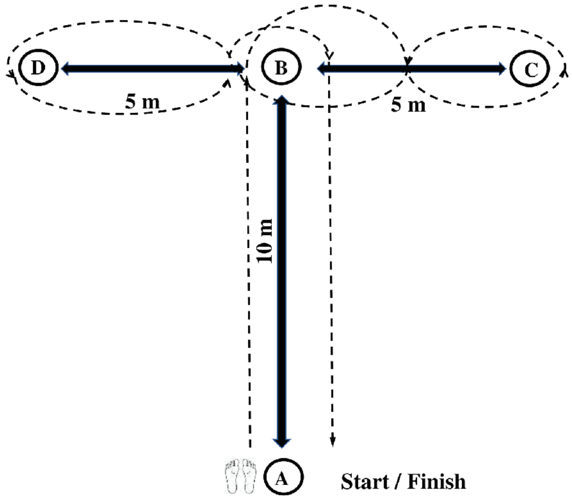

Figure 2. The configuration of the modified version of the agility T-test was used to assess change-of-direction speed time. Cones at a height of 0.64 m were placed at points A, B, C, and D with participants being instructed to sprint from A to B, perform a 90˚ turn from cone B towards cone C, then perform a 180˚ turn at cone C towards cone B, before performing a weave at cone B towards cone D, then performing a 180˚ turn at cone D towards cone B, and finally a 90˚ turn to the start/finish line. The participants were required to turn/weave around the cones without touching them. Trials were discarded if the cones were displaced while changing direction with participants being required to repeat the trial after 3 min of rest (i.e., standing/walking slowly). The participants completed the test with their back always facing the start-finish line

Note: black dotted line denotes the pattern of movement during the test.

Casio Computer Co., Ltd., Tokyo, Japan). The average time recorded by both timekeepers was used for analysis. Three trials were performed with three-minute rest between trials, and the fastest trial was selected for analysis. The ICC for test-retest reliability was 0.99 (95% CI: 0.98–0.99).

Isokinetic strength tests

The tests were conducted on a validated HUMAC NORM isokinetic dynamometer (Computer Sports Medicine Inc., Stoughton, USA) [16]. A general 10-minute 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, i.e., all knee extension and flexion movements involved concentric actions. The right side was always selected first across all testing sessions. The test protocol included a set of six repetitions at 60°/seconds. Two sets were completed for each leg with one minute 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 value obtained was selected for analysis. The ICC for test-retest reliability was 0.99 (95% CI: 0.95–0.99) for right knee extension, 0.97 (95% CI: 0.92–0.99) for right knee flexion, 0.99 (95% CI: 0.98–0.99) for left knee extension, and 0.98 (95% CI: 0.92–0.99) for left knee flexion.

Statistical analyses

The analyses were conducted using IBM SPSS version 20.0.0 (IBM, New York, USA). Data are presented as means and standard deviations. Data normal distribution and its homogeneity of variance was verified using the Shapiro-Wilk test and the Levene's test for equality of variances, respectively. ANCOVA with baseline scores as a covariate was used to analyze the exercise-specific effects. For significant differences, post-hoc pairwise comparisons were conducted to find which group was favored. Within group, changes were analyzed using a paired t-test. Percentage change scores were also calculated for each variable in each group using the equation in Microsoft Excel: $[(mean_{post} - mean_{pre}) / mean_{pre}] \times 100$. Effects sizes (ES) in the form of partial eta squared (η_p^2) were used from ANCOVA output. Hedge's *g* deriving from paired t-tests were calculated to assess changes between pre-post measurements testing for each group. The magnitude of effects for η_p^2 was interpreted as small (<0.06), moderate

Table 3. Statistical comparisons between experimental and control groups

	Complex-contrast training group (n = 8)			Control group (n =6)			ANCOVA
	Pre-test	Post-test	***p*-value [g]**	Pre-test	Post-test	***p*-value [g]**	***p*-value [η_p^2]**
	Mean ± SD		***Magnitude***	Mean ± SD		**Magnitude**	***Magnitude***
30 m sprint [s]	4.83 ± 0.15	4.68 ± 0.16	<0.001 [0.91] *Moderate*	4.80 ± 0.33	4.76 ± 0.27	0.264 [.12] *Trivial*	0.013 [0.44] *Large*
Medicine ball throw [m]	9.76 ± 0.84	10.31 ± 0.89	<0.001 [0.60] *Small*	9.77 ± 0.46	9.95 ± 0.61	0.169 [.31] *Small*	0.057 [0.29] *Large*
Standing long jump [m]	2.35 ± 0.13	2.46 ± 0.14	0.001 [0.77] *Moderate*	2.20 ± 0.15	2.22 ± 0.19	0.404 [.19] *Trivial*	0.141 [0.19] *Large*
Countermovement jump with arms swing [cm]	36.4 ± 2.4	41.2 ± 3.5	<0.001 [1.52] *Large*	38.0 ± 3.1	37.1 ± 2.4	0.355 [.32] *Small*	0.003 [0.57] *Large*
Change of direction speed (MAT) [s]	6.39 ± 0.30	5.35 ± 0.43	<0.001 [2.65] *Very large*	6.30 ± 0.35	6.30 ± 0.34	0.991 [.00] *Trivial*	<0.001 [0.73] *Large*
PT knee extension (right) [N · m]	143.3 ± 58.1	160.1 ± 59.6	<0.001 [0.27] *Small*	170.2 ± 23.5	170.5 ± 23.3	0.853 [.01] *Trivial*	<0.001 [0.81] *Large*
PT knee extension (left) [N · m]	149.4 ± 48.7	164.4 ± 51.3	<0.001 [0.28] *Small*	157.0 ± 31.4	157.5 ± 30.6	0.830 [.01] *Trivial*	0.001 [0.67] *Large*
PT knee flexion (right) [N · m]	90.4 ± 24.0	98.9 ± 26.3	<0.001 [0.32] *Small*	91.2 ± 21.5	91.5 ± 23.6	0.851 [.01] *Trivial*	0.003 [0.57] *Large*
PT knee flexion (left) [N · m]	92.6 ± 23.3	100.0 ± 23.2	<0.001 [0.30] *Small*	83.5 ± 10.5	83.2 ± 10.7	0.775 [.03] *Trivial*	0.001 [0.68] *Large*

Note: g – Hedges' g; η_p^2 – partial eta squared; MAT – modified agility T-test, [N · m] – Newton meters; PT – peak torque.

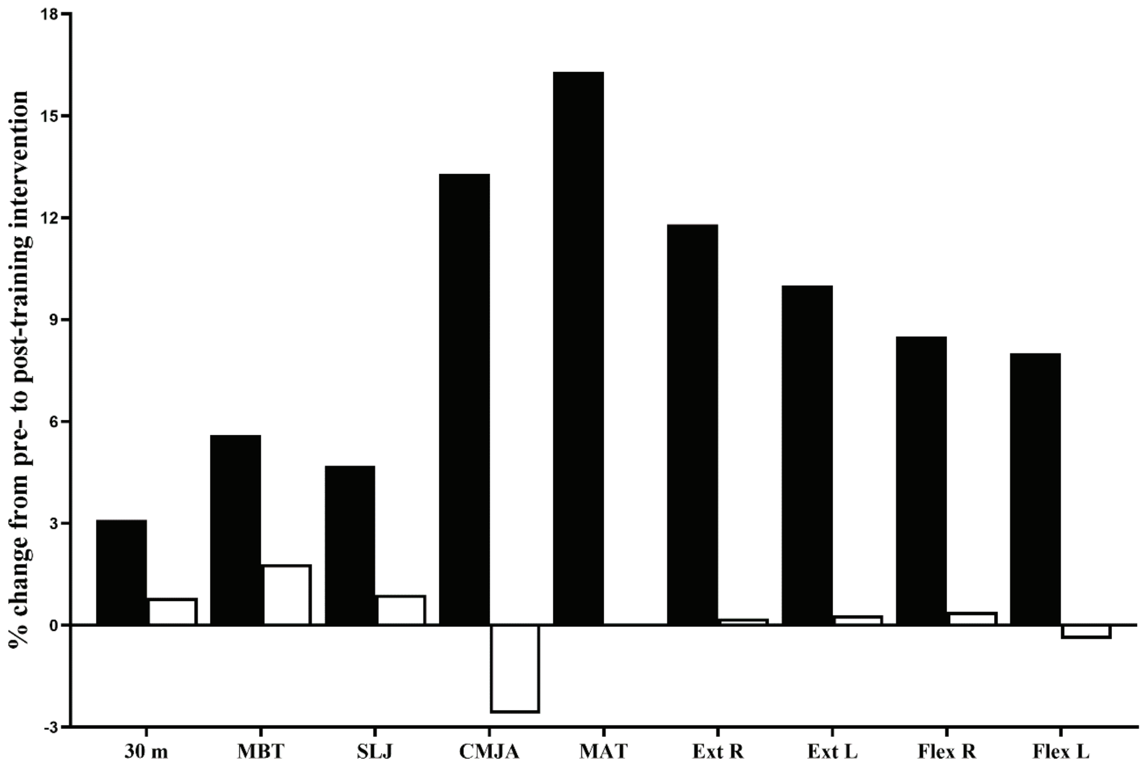

Figure 3. Relative (%) change in dependent variables between pre- and post-training intervention for the complex-contrast training (black bars) and control group (white bars)

Note: negative bars denote detrimental changes; CMJA: countermovement jump height with arm swing; Ext: knee extension for maximal torque; Flex: knee flexion for maximal torque; L: left; MAT: modified agility T-test time; MBT: medicine ball throw for distance; R: right; SLJ: standing long jump distance.

(≥0.06–0.13), and large (≥0.14) [9], 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) [19]. 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% CI ($ICC_{95\%CI\ lower\ bound}$) [22]. Statistical significance was set at $p \leq 0.05$.

Results

Adverse effects

No participants dropped out, sustained injuries, or missed training sessions, during this study.

Main outcomes

No baseline differences (independent t-test p = 0.06–0.991) were observed between the CCT group and the CG in any dependent variables.

There were significant differences between the CCT group and CG in 30 m sprint, CMJA, MAT, and isokinetic strength (p < 0.001–0.013) after a six-week intervention favoring the CCT group. Further post-hoc tests using paired t-tests revealed significant pre-post improvements in all dependent variables in the CCT group (all p < 0.001–0.001; g = 0.27–2.65; %Δ = 3.1–16.3), but not in the CG (all p = 0.169–0.991; g = 0.00–0.32; %Δ = 0.0–2.6). No differences were observed between the CCT group and CG for MBT (p = 0.057) and SLJ (0.141) after the six-week intervention. A graphical representation of pre-post intervention physical fitness changes in the CCT group and CG is available in Figure 3.

Discussion

This study aimed to examine the effects of a six-week CCT intervention on the physical fitness of male field hockey athletes. The main findings indicated that a six-week CCT intervention in place of regular field hockey training improved 30 m linear sprint time, CMJA height, MAT time, and isokinetic strength compared to regular hockey training. The magnitude of pre-post improvement in the CCT group was *small* for the four peak isokinetic torque measurements (%Δ = 5.6–11.8), *moderate* for 30 m sprint time (%Δ = 3.1), *large* for CMJA height (%Δ = 13.3), and *very large* for MAT time (%Δ = 16.3).

No significant differences were observed between groups in MBT and SLJ distance.

Although the literature on CCT for field hockey athletes is scarce, the current findings are in line with previous studies conducted on soccer athletes with similar characteristics [1, 6]. Ali et al. [1] conducted a six-week CCT intervention on university-level male soccer athletes (aged ~22 years) and reported *moderate* improvements in 20 m linear sprint time and CMJ height compared to a CG. Similarly, Brito et al. [6] reported *small* to *moderate* improvements in the 20 m linear sprint, peak torque of the dominant leg during knee extension and flexion after a nine-week CCT intervention. With youth field hockey athletes (aged 12–14), Moran et al. [27] also reported improvements in sprint acceleration after a six-week plyometric training intervention. The increase in performance in the CCT group 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 [11, 12, 39]. Indeed, the incorporation of high-load low velocity and low-load high-velocity exercise during CCT (e.g., 85%1RM squat with CMJ) induces specific adaptations that optimize the force-velocity relationship [12]. Moreover, the isolated application of heavy resistance or plyometric exercises would specifically target the force or velocity component of the force-velocity spectrum [12]. However, including both resistance and plyometric exercises in a single training session (i.e., CCT), may enable athletes to improve across the force-velocity spectrum [12, 40]. Furthermore, optimizing the force-velocity relationship helps recruit fast-twitch muscle fibers that underpin athletic performance (e.g., sprints, jumps) [21, 25].

Additionally, previous studies have also reported hormonal and structural adaptations such as increased testosterone concentration [1] and increased leg volume [18] following a six-week CCT intervention in male soccer players. The aforementioned reasons 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 mechanistic rationale, another mechanism that may have contributed to the beneficial effects of the CCT is the PAPE phenomenon [5, 12, 29]. It is suggested that the high-load activity stimulates an increase in the calcium in the myoplasm of the muscle fiber, activating the myosin light chain kinase which phosphorylates the light chains, thereby promoting increased actin-myosin cross-bridges [5, 12, 29, 30] which has a potentiation effect on the lower-load activity. Indeed, a recent meta-analysis has confirmed that using high-load resistance exercises and low-load plyometric exercises in a CCT format is superior (i.e., greater effect size) to performing the exercise combination in other formats (e.g., complex-descending training) in improving sprints, jumps, change of direction, and maximal strength [13]. Therefore, sequencing exercises in a CCT format may have contributed to the enhanced performance of field hockey athletes in this study. But whether this would also be the case for other sequencing methods of complex training requires further investigation.

There are limitations of this study that should be acknowledged. First, we were unable to compare our findings with prior CCT studies in field hockey due to the paucity of evidence in this area. However, the original and novel evidence presented in this study will form a basis for future research on field hockey players. Second, the training intervention was limited to a six-week duration. Although significant improvements were observed in the CCT group, a longer duration study may be needed to determine the long-term adaptions in field hockey athletes. Third, this study included a small sample size. Although we conducted a sample size estimation before conducting the study, a larger sample size may be required to support the current findings. Fourth, we used hand stop watches to measure the sprint and MAT timings. Although we observed excellent between timekeeper's reliability, the use of an electronic (e.g., photocells) or video-based (e.g., MySprint) timing system may provide greater precision. Finally, no biochemical or physiological data was collected. Such data would provide further insights into the mechanistic aspects of the reported results.

Conclusion

Compared to an active control group of amateur male athletes undergoing regular field hockey training and conditioning drills, athletes that incorporated CCT into their regular field hockey training program improved 30 m linear sprint time, CMJA height, MAT time, and maximal isokinetic strength. Therefore, CCT may be suggested as a supplementary training intervention to regular field hockey training, potentially inducing neuromuscular adaptations (e.g., sprints, vertical jumps, change of direction speed, strength) in favor of maximal-intensity short-duration actions commonly occurring during matches.

Conflict of interest: Authors state no conflict of interest.

References

1. Ali K., Verma S., Ahmad I., Singla D., Saleem M., Hussain M.E. (2019) Comparison of complex versus contrast training on steroid hormones and sports performance in male soccer players. *J. Chiropr. Med.,* 18: 131-138. DOI: 10.1016/j.jcm.2018.12.001

2. Astorino T.A., Tam P.A., Rietschel J.C., Johnson S.M., Freedman T.P. (2004) Changes in physical fitness parameters during a competitive field hockey season. *J. Strength Cond. Res.*, 18: 850-854. DOI: 10.1519/13723.1
3. Begg C., Cho M., Eastwood S., Horton R., Moher D., Olkin I., Pitkin R., Rennie D. et al. (1996) Improving the quality of reporting of randomized controlled trials. The CONSORT statement. *Jama*, 276: 637-639. DOI: 10.1001/jama.276.8.637
4. Bishop C., Brazier J., Cree J., Turner A. (2015) A needs analysis and testing battery for field hockey. *Professional Strength and Conditioning,* 36: 15-26.
5. Blazevich A.J., Babault N. (2019) Post-activation potentiation versus post-activation performance enhancement in humans: Historical perspective, underlying mechanisms, and current issues. *Front. Physiol.,* 10: 1359. DOI: 10.3389/fphys.2019.01359
6. Brito J., Vasconcellos F., Oliveira J., Krustrup P., Rebelo A. (2014) Short-term performance effects of three different low-volume strength-training programmes in college male soccer players. *J. Hum. Kinet.*, 40: 121-128. DOI: 10.2478/hukin-2014-0014
7. Cavaco B., Sousa N., Dos Reis V.M., Garrido N., Saavedra F., Mendes R., Vilaça-Alves J. (2014) Short-term effects of complex training on agility with the ball, speed, efficiency of crossing and shooting in youth soccer players. *J. Hum. Kinet.,* 43: 105-112. DOI: 10.2478/hukin-2014-0095
8. Chaabene H., Negra Y., Sammoud S., Moran J., Ramirez-Campillo R., Granacher U., et al. (2021) The effects of combined balance and complex training versus complex training only on measures of physical fitness in young female handball players. *Int. J. Sports Physiol. Perform.,* 16: 1439-1446. DOI: 10.1123/ijspp.2020-0765
9. Cohen J. (1988) *Statistical Power Analysis for the Behavioral Sciences.* Second ed. Hillsdale: Lawrence Erlbaum Associates.
10. Cormie P., McGuigan M.R., Newton R.U. (2011) Developing maximal neuromuscular power: Part 1-biological basis of maximal power production. *Sports Med.,* 41: 17-38. DOI: 10.2165/11537690-000000000-00000
11. Cormie P., McGuigan M.R., Newton R.U. (2011) Developing maximal neuromuscular power: part 2 – training considerations for improving maximal power production. *Sports Med.,* 41: 125-146. DOI: 10.2165/11538500-000000000-00000
12. Cormier P., Freitas T.T., Loturco I., Turner A., Virgile A., Haff G.G., Blazevich A.J., Agar-Newman D., et al. (2022) Within session exercise sequencing during programming for complex training: historical perspectives, terminology, and training considerations. *Sports Med.,* 52: 2371-2389. DOI: 10.1007/s40279-022-01715-x
13. Cormier P., Freitas T.T., Rubio-Arias J., Alcaraz P.E. (2020) Complex and contrast training: Does strength and power training sequence affect performance-based adaptations in team sports? A systematic review and meta-analysis. *J. Strength Cond. Res.,* 34: 1461-1479. DOI: 10.1519/jsc.0000000000003493
14. Elferink-Gemser M.T., Visscher C., Lemmink K.A., Mulder T. (2007) Multidimensional performance characteristics and standard of performance in talented youth field hockey players: a longitudinal study. *J. Sports Sci.,* 25: 481-489. DOI: 10.1080/02640410600719945
15. Faude O., Roth R., Di Giovine D., Zahner L., Donath L. (2013) Combined strength and power training in high-level amateur football during the competitive season: a randomised-controlled trial. *J. Sports Sci.,* 31: 1460-1467. DOI: 10.1080/02640414.2013.796065
16. Habets B., Staal J.B., Tijssen M., van Cingel R. (2018) Intrarater reliability of the Humac NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles. *BMC Res. Notes,* 11: 15. DOI: 10.1186/s13104-018-3128-9
17. Haff G.G., Nimphius S. (2012) Training Principles for Power. *Strength Cond. J.,* 34: 2-12. DOI: 10.1519/SSC.0b013e31826db467
18. Hammami M., Negra Y., Shephard R.J., Chelly M.S. (2017) The effect of standard strength vs. contrast strength training on the development of sprint, agility, repeated change of direction, and jump in junior male soccer players. *J. Strength Cond. Res.,* 31: 901-912. DOI: 10.1519/jsc.0000000000001815
19. Hopkins W.G., Marshall S.W., Batterham A.M., Hanin J. (2009) Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.,* 41: 3-13. DOI: 10.1249/MSS.0b013e31818cb278
20. Jennings D.H., Cormack S.J., Coutts A.J., Aughey R.J. (2012) International field hockey players perform more high-speed running than national-level counterparts. *J. Strength Cond. Res.,* 26: 947-952. DOI: 10.1519/JSC.0b013e31822e5913
21. Jiménez-Reyes P., Garcia-Ramos A., Párraga-Montilla J.A., Morcillo-Losa J.A., Cuadrado-Peñafiel V., Castaño-Zambudio A., Samozino P., Morin J.B. (2022) Seasonal changes in the sprint acceleration force-velocity profile of elite male soccer players. *J. Strength Cond. Res.,* 36: 70-74. DOI: 10.1519/jsc.0000000000003513
22. Koo T.K., Li M.Y. (2016) A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.*, 15: 155-163. DOI: 10.1016/j.jcm.2016.02.012
23. Kumar G., Pandey V., Thapa R.K., Weldon A., Granacher U., Ramirez-Campillo R. (2023) Effects of exercise frequency with complex contrast training on measures of physical fitness in active adult males. *Sports* (Basel), 11: 11. DOI: 10.3390/sports11010011
24. Lythe J., Kilding A.E. (2011) Physical demands and physiological responses during elite field hockey. *Int. J. Sports Med.,* 32: 523-528. DOI: 10.1055/s-0031-1273710

25. Macaluso F., Isaacs A.W., Myburgh K.H. (2012) Preferential type II muscle fiber damage from plyometric exercise. *J. Athl. Train.,* 47: 414-420. DOI: 10.4085/1062-6050-47.4.13
26. Maher C.G., Sherrington C., Herbert R.D., Moseley A.M., Elkins M. (2003) Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys. Ther.,* 83: 713-721.
27. Moran J., Ramirez-Campillo R., Granacher U. (2018) Effects of jumping exercise on muscular power in older adults: a meta-analysis. *Sports Med.,* 48: 2843-2857. DOI: 10.1007/s40279-018-1002-5
28. Moran J., Sandercock G.R.H., Ramírez-Campillo R., Todd O., Collison J., Parry D.A. (2017) Maturation-related effect of low-dose plyometric training on performance in youth hockey players. *Pediatr. Exerc. Sci.,* 29: 194-202. DOI: 10.1123/pes.2016-0151
29. Prieske O., Behrens M., Chaabene H., Granacher U., Maffiuletti N.A. (2020) Time to differentiate postactivation "Potentiation" from "Performance Enhancement" in the strength and conditioning community. *Sports Med.,* 50: 1559-1565. DOI: 10.1007/s40279-020-01300-0
30. Sale D.G. (2002) Postactivation potentiation: role in human performance. *Exerc. Sport Sci. Rev.,* 30: 138-143. DOI: 10.1097/00003677-200207000-00008
31. Sassi R.H., Dardouri W., Yahmed M.H., Gmada N., Mahfoudhi M.E., Gharbi Z. (2009) Relative and absolute reliability of a modified agility T-test and its relationship with vertical jump and straight sprint. *J. Strength Cond. Res.,* 23: 1644-1651. DOI: 10.1519/JSC.0b013e3181b425d2
32. Sharma H.B., Kailashiya J. (2018) Effects of 6-Week Sprint-Strength and Agility Training on Body Composition, Cardiovascular, and Physiological Parameters of Male Field Hockey Players. *J. Strength Cond. Res.,* 32: 894-901. DOI: 10.1519/jsc.0000000000002212
33. Singh G., Kushwah G., Singh T., Ramirez-Campillo R., Thapa R.K. (2022) Effects of six weeks outdoor versus treadmill running on physical fitness and body composition in recreationally active young males: a pilot study. *PeerJ.*, 10: e13791:
34. Singh G., Kushwah G.S., Singh T., Thapa R.K., Granacher U., Ramirez-Campillo R. (2022) Effects of sand-based plyometric-jump training in combination with endurance running on outdoor or treadmill surface on physical fitness in young adult males. *J. Sports Sci. Med.,* 21: 277-286. DOI: 10.52082/jssm.2022.277
35. Smart N.A., Waldron M., Ismail H., Giallauria F., Vigorito C., Cornelissen V., Dieberg G. (2015) Validation of a new tool for the assessment of study quality and reporting in exercise training studies: TESTEX. *Int. J. Evid. Based Health*, 13: 9-18. DOI: 10.1097/XEB.0000000000000020
36. Taylor J.B., Wright A.A., Dischiavi S.L., Townsend M.A., Marmon A.R. (2017) Activity demands during multi-directional team sports: A systematic review. *Sports Med.,* 47: 2533-2551. DOI: 10.1007/s40279-017-0772-5
37. Thapa R.K., Kumar A., Kumar G., Narvariya P. (2020) A combination of ballistic exercises with slow and fast stretch-shortening cycle induces post-activation performance enhancement. *Trends Sports Sci.,* 27: 203-211. DOI: 10.23829/TSS.2020.27.4-3
38. Thapa R.K., Kumar G. (2023) Does complex contrast training induce higher physical fitness improvement in stronger compared to weaker individuals? *Montenegrin J. Sports Sci. Med.,* 12: Ahead of Print. DOI: 10.26773/mjssm.230306
39. Thapa R.K., Lum D., Moran J., Ramirez-Campillo R. (2021) Effects of complex training on sprint, jump, and change of direction Ability of soccer players: A systematic review and meta-analysis. *Front. Psychol.,* 11: 627869. DOI: 10.3389/fpsyg.2020.627869
40. Thapa R.K., Narvariya P., Weldon A., Talukdar K., Ramirez-Campillo R. (2022) Can complex contrast training interventions improve aerobic endurance, maximal strength, and repeated sprint ability in soccer players? A systematic review and meta-analysis. *Montenegrin J. Sports Sci. Med.,* 11: 45-55. DOI: 10.26773/mjssm.220906
41. Turner A.N., Comfort P., McMahon J., Bishop C., Chavda S., Read P., Mundy P. Lake J. (2020) Developing powerful athletes, part 1: mechanical underpinnings. *Strength Cond. J.,* 42: 30-39. DOI: 10.1519/SSC.0000000000000543
42. Weldon A., Duncan M.J., Turner A., Sampaio J., Noon M., Wong D.P., Lai V.W. (2021) Contemporary practices of strength and conditioning coaches in professional soccer. *Biol. Sport,* 38: 377-390. DOI: 10.5114/biolsport.2021.99328

Received 15.04.2023
Accepted 28.07.2023