Efficacy of Combined General, Special, and Specific Resistance Training on Pace Bowling Skill in Club-Standard Cricketers

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ABSTRACT

Feros, SA, Young, WB, and O’Brien, BJ. Efficacy of combined general, special, and specific resistance training on pace bowling skill in club-standard cricketers. J Strength Cond Res XX(X): 000–000, 2018—This study investigated the efficacy of combined “general,” “special,” and “specific” resistance training on pace bowling skill. Twelve male, club-standard pace bowlers were randomly allocated to a combined resistance training (CRT) program or traditional cricket training (TCT) program for 8 weeks. The CRT group (n = 6) trained with 300, 250-g, and standard cricket balls; performed 20-m sprints with +20% and +15% body mass resistance (but also unresisted); and completed chin-up and pull-up training. The TCT group (n = 6) trained with standard balls and performed unresisted 20-m sprints. No statistically significant GROUP × TIME interactions were identified. The CRT group demonstrated a “clear moderate” enhancement in peak ball release speed (mean ± 95% confidence limits [CLs]: 1.2 ± 1.5 m·s⁻¹, d = 0.66 ± 0.83), a “clear large” increase in mean radial error (mean ± 95% CLs: 7.1 ± 6.5 cm, d = 0.94 ± 0.87), and a “clear large” rise in bivariate variable error (mean ± 95% CLs: 7.2 ± 7.8 cm, d = 0.97 ± 1.05). The TCT group exhibited “unclear” changes across all pace bowling skill measures. Both groups displayed “unclear” changes in approach speed, 20-m sprint time, and 1 repetition maximum pull-up strength. In 8 weeks, the CRT program improved peak ball release speed, but at the cost of poorer bowling accuracy and consistency of bowling accuracy. These findings could be attributed to bowling with the heavier balls. The inclusion of “specific” resistance training does not seem to be effective in enhancing all-round pace bowling skill in club-standard cricketers.

KEY WORDS accuracy, speed, modified-implement training, sprint training, strength training, performance

INTRODUCTION

Pace bowling is a specialist role within the cricket team, where the objective is to minimize runs scored by opposition batters and to also dismiss them (i.e., get them "out"); known a wicket). There are many factors comprising cricket pace bowling performance during match play, such as wickets taken, strike rate (runs conceded per wicket), and economy (average runs scored per over). An elite pace bowler should have the necessary skill to bowl quickly, accurately, and consistently fast and accurately (44) during a bowling spell (series of overs; an over is equivalent to 6 legal deliveries) or repeated bowling spells throughout a match. A faster delivery speed simply reduces a batter’s reaction time and movement time (48), which may result in a greater likelihood of the batter not striking the ball or mistiming the ball strike. Consistent, fast bowling speeds maintain this advantage throughout a bowling spell or match, regardless of deliberate changes up and down in ball release speed from the bowler, which are critical for deceiving a batter. On the other hand, an accurate delivery refers to a ball that follows the pace bowlers’ intended trajectory (i.e., line of ball flight and length of where the ball lands on the cricket pitch) (32). If a pace bowler can identify the technical faults of the batter, then an accurate delivery can result in a dismissal or reduce the amount of runs scored from that delivery. Consistent, accurate bowling can make it difficult for batters to score throughout a bowling spell, which can lead to an increase in scoring pressure, and poorer decision-making and stroke play from the batter.

To achieve these skills, pace bowlers adopt a 15–30-m run-up, followed by a jump into a back foot and front foot landing, executed in a split-leg manner (stride) similar to baseball pitchers or javelin throwers. Although there are many different pace bowling techniques and classifications (18), there is mounting evidence to suggest that a faster approach speed (i.e., run-up speed) is positively and
significantly associated with higher ball release speeds (15,17,23). In support, Ferdinands et al. (17) reported that approach speed contributes 11.7% to ball release speed. In addition, recent evidence has shown acceleration speed, as assessed by a 20-m sprint test, is moderately associated with ball release speed in club-standard pace bowlers (22). Collectively, this research highlights the need for an intervention to develop run-up speed and subsequently evaluate the changes in ball release speed. Such an intervention has not been trialled previously in cricket pace bowling research.

Recently, Feros et al. (22) reported a large positive correlation between 1 repetition maximum (1RM) pull-up strength and ball release speed in club-standard pace bowlers. The authors suggested that the pull-up exercise targets similar muscles to those involved in cricket pace bowling (41), and that enhancing the strength of these muscles may contribute to the torque produced by the glenohumeral joint when rotating the bowling arm. Improving the torque produced by the glenohumeral joint during circumduction may be quite important to enhance ball release speed, as surprisingly, Glazier et al. (23) reported a non-statistically significant relationship between angular velocity of the bowling arm humerus and ball release speed. Therefore, strength training with the goal to develop upper-body pulling strength may contribute to faster bowling speeds.

A majority of the research in pace bowling skill have used cross-sectional designs, comprising correlational or multiple regression analyses between ball release speed and time discrete biomechanical variables (17,23,30,36,51), selected physical capacities (30,36,37), and anthropometric variables (23,36,37). Although this type of research provides foundational evidence for strength and conditioning coaches to use in testing and program design, there is a need for randomized controlled trials, as correlation does not infer causation (52). Surprisingly, only 2 training-related randomized controlled trials have been implemented in cricket pace bowling to date (35,47). Both studies examined the effects of modified-implement bowling on bowling speed and accuracy in subelite cricketers (35,47). Petersen et al. (35) observed a 1.1 m·s⁻¹ increase in bowling speed and a 7% decline in bowling accuracy after 10 weeks of modified-implement training with balls of 84–116% of standard mass. By contrast, Wickington and Linthorne (47) reported a 0.9 m·s⁻¹ enhancement in bowling speed but a “substantially beneficial” increase in bowling accuracy after 8 weeks of modified-implement training with balls of 46–157% of standard mass. The discrepancy in bowling accuracy between studies may simply be attributable to methodological differences in pace bowling assessment and calculation of bowling accuracy (21). Petersen et al. (35) measured bowling accuracy through by defining whether the delivery was successful or unsuccessful in landing the ball 6–7 m from the stumps, whereas Wickington and Linthorne (47) adopted a points-based scoring system with a vertical target sheet positioned in line with the stumps at the batting end. Interestingly, 3 of the 5 subjects in the modified-implement training program of Wickington and Linthorne (47) displayed “unclear” changes in bowling accuracy, and so, the overall finding of “substantially beneficial increase in bowling accuracy” was likely biased by 2 subjects who demonstrated bigger improvements in bowling accuracy.

Contrary to previous recommendations that modified-implement mass should only be ±20% of standard mass (16), Wickington and Linthorne (47) speculated that changes in ball release speed of at least ±5% with modified implements to be a necessary training stimulus to develop ball release speed. In their study, they calculated the maximum changes in ball mass of −54% and +37% to produce changes in ball release speed of 0.9 m·s⁻¹ and −0.6 m·s⁻¹, respectively, equivalent to a +3% and −2% respective change in ball release speed with a standard mass ball (47). The authors speculated that training with a range of modified cricket balls from 80–400 g may provide an appropriate stimulus to develop ball release speed without significantly altering bowling technique or bowling accuracy (47).
Previous research and coaching literature indicates that modified-implement training can enhance implement velocity in throwing-related sports such as baseball (12,13), javelin (6), shot put (24), and discus (2). Using modified implements is a form of “specific” training (14), designed to assist the athlete with coordinating body segments at faster speeds with a lighter implement, whereas the heavier implement is believed to enhance the strength (i.e., provide resistance) that is required to attain these higher speeds (16). Although modified-implement training may be somewhat effective in enhancing bowling speed (35,47), “general” and “special” resistance training exercises (designed to improve muscular strength and power, respectively) are also effective in improving throwing speed in baseballers (14), and thus warrant further investigation in cricket pace bowling. Interestingly, a combination of general, special, and specific resistance training exercises throughout one mesocycle has been reported to enhance throwing speed in baseballers by 5.6% (43). It is not understood whether this combined resistance training (CRT) approach is more effective in improving pace bowling skill and approach speed compared with traditional forms of cricket training (e.g., bowling and sprinting). Therefore, the purpose of this study was to determine the efficacy of combined general, special, and specific resistance training on pace bowling skill and approach speed.

**METHODS**

**Experimental Approach to the Problem**

The study involved a randomized controlled trial design over a 12-week period through the cricket off-season (July–September). All subjects had not engaged in pace bowling for 3 months (April–June), leading up to the study. Nine of the subjects were also not engaged in resistance training during this period, whereas the other 3 subjects were partially committed to a strength endurance training program of 1–2 sessions per week in this lead-up phase.

The first 2 weeks of the study comprised 4 familiarization sessions (2 sessions per week) for subjects to become more comfortable and confident with heavier ball bowling, sprint technique, sprinting with a weighted vest, pull-up training and technique, the pace bowling test (e.g., targets and delivery sequence), swing characteristics of the cricket balls, and ball bounce characteristics of the synthetic grass pitch used in the pace bowling test. This 2-week block also served to safely increase bowling and sprinting workload for the upcoming training intervention. Testing periods involved one session per week in the third and 12th week of the study. The session comprised a 4-over pace bowling assessment (6 deliveries per over equaling 24 deliveries), 20-m sprint, and 1RM pull-up spread out over 90 minutes.

Subjects were randomly but evenly assigned to one of 2 training groups, CRT and traditional cricket training (TCT), by ranking of peak ball release speed (from highest to lowest). Subjects were paired by rank (i.e., ranks 1 and 2 paired, 3 and 4 paired, etc.) and then randomly allocated to either group through a formula within a purpose-made Microsoft Excel spreadsheet (version 2016; Microsoft Corp., Redmond, WA, USA). This procedure meant that there were no statistically significant differences in peak ball release speed at the pre-test period. The CRT group
(n = 6) completed bowling with standard (156 g) and heavy implements (250 and 300 g), acceleration speed training (unresisted, +20 and +15% body mass vest), and pull-ups. None of the subjects received technical coaching on bowling and sprinting during the study. Subjects were required to wear their own hard wicket cricket shoes for all testing and training sessions. Bowling and sprint volume were matched between groups. Both groups completed 2 sessions per week from weeks 4 to 11 (inclusive). Sessions were separated by 48–72 hours of recovery. An Accredited Strength and Conditioning Coach (level 2, Australian Strength and Conditioning Association) supervised all training sessions. Before each testing and training session, subjects were instructed to refrain from alcohol and caffeine consumption for a 24-hour period, as well as any form of resistance training for a 48-hour period. Ambient temperature was controlled indoors and ranged from 19 to 21°C throughout testing and training sessions.

Subjects
Twenty-one male amateur community-standard pace bowlers from the Ballarat Cricket Association (n = 19, A and B grade standard) and Victorian Premier League Competition (n = 2, Second and Fourth Grade) participated in this investigation. Subjects were included if they were male, between 16 and 40 years of age, and injury-free at least 6 months before the conduction of the study. Nine subjects were withdrawn from the study; 5 sustained an injury (externally), and 4 did not meet acceptable training attendance (87.5% adherence). Of the remaining 12 subjects, 11 were right-handed bowlers, and one was a left-handed bowler. The age, body mass, bowling experience, and structured resistance training experience for these 12 subjects were (mean ± SD) 23.7 ± 7.5 years (range 16–39 years), 83.5 ± 13.0 kg, 7.1 ± 4.7 cricket seasons, and 1.5 ± 2.9 years, respectively. Subjects were informed of the risks and benefits of the study before any data collection. All procedures were approved by the University of Australia’s Human Research Ethics Committee (project number: A12-086), and written informed consent was obtained for each subject or parent/guardian before the commencement of the study.

Procedures

Warm-ups. Testing sessions commenced with a 5-minute general warm-up comprising light-moderate aerobic activities, and dynamic stretches for the legs, lumbar and thoracic regions, and arms (20). A specific bowling warm-up followed, where subjects completed 33 deliveries of gradual intensity (60, 70, 80, 90, and 95% perceived effort) and from a shortened and full run-up (20).

Pace Bowling Test. The pace bowling test commenced 3 minutes after the specific bowling warm-up. The test was truncated from an 8-over version (19) to 4 overs (24 legal deliveries) to reduce assessment time. The reliability and sensitivity data were obtained for the 4-over test in a smaller but similar sample (n = 13) of club-standard pace bowlers (Table 1). A new 156-g 2-piece red cricket ball (Tuf Pitch, Kookaburra, Melbourne, Australia) was used in the assessment. The test was performed through the same procedures for the 8-over version (19), except for the exclusion of the “live” batter due to previous limitations outlined (19). Timing was monitored on an iPad 2 (Apple Inc., CA, USA) with the “LabTimer” application.

Ball release speed of each delivery was measured by a radar gun (Stalker Pro; Applied Concepts, TX, USA) following established procedures (19), with a cosine error correction of 0.906 applied to ball release speed data, due to the 25° angle of the radar gun (21). Three variables were calculated from the bowling speed data: (a) peak ball release speed; the mean of the 2 maximal-effort deliveries, (b) mean ball release speed; comprising all 20 match-intensity deliveries, and (c) variability of ball release speed, the SD of 20 match-intensity deliveries (19). Maximal-effort and slower-ball deliveries were omitted from mean ball release speed and variability of ball release speed calculations (19). The accuracy of each delivery was captured by a digital high-definition video camera (Sony HXR-MC50P; Sony Corp., Tokyo, Japan) that operated at 25 frames per second and
with a shutter speed of 0.02 seconds. Although this frame rate is relatively low, identification of ball strike was made easier with the placement of a high jump mat directly behind the target sheet. During pilot testing, we trialled a range of speeds expected of the sample (27.8–34.7 m·s⁻¹) and determined that 25 frames per second was suitable to detect the moment of ball impact on the target sheet, when viewed frame by frame on Dartfish Connect (version 7; Dartfish, Melbourne, Australia). Two variables were calculated from the bowling accuracy data: (a) mean radial error from 20 match-intensity deliveries, and (b) bivariate variable error; from 16 match-intensity deliveries pooled from both off-stump targets (19). Delivery rating of perceived effort was obtained each delivery following previously outlined procedures (19). Run-up speed was measured by a dual-beam electronic timing system (Swift Performance Equipment, Lismore, New South Wales, Australia), with a timing resolution of 0.01 second, positioned at 0 and 20 m. Subjects sprinted on synthetic turf (12-mm pile height) that overlayed a concrete floor. For each sprint, subjects adopted a stationary split stance technique, with the preferred leg positioned at the start line and opposite arm forward. They were instructed to not rock backward and forward before the sprint. Excellent reliability for 20-m sprint time has been reported by Lockie et al. (29), with an intraclass correlation coefficient (ICC) of 0.96, smallest worthwhile change of 0.06 seconds, and smallest worthwhile change of 0.09 seconds.

**Acceleration Speed Assessment.** After 10 minutes of passive recovery after the pace bowling test, subjects completed a 20-m sprint test, for assessment of acceleration speed (54). Before the test, subjects completed a sprint warm-up of 5 × 20-m sprints from a stationary start (on every minute), at 60, 70, 80, 90, and 95% perceived effort, with a walk-back recovery. One maximal-effort 20-m sprint was performed 3 minutes after the sprint warm-up. Subjects were instructed to “sprint as fast as possible.” Twenty-meter sprint time was measured using 2 pairs of dual-beam electronic timing gates (Swift Performance Equipment), with a timing resolution of 0.01 seconds, positioned at 0 and 20 m. Subjects sprinted on synthetic turf (12-mm pile height) that overlayed a concrete floor. For each sprint, subjects adopted a stationary split stance technique, with the preferred leg positioned at the start line and opposite arm forward. They were instructed to not rock backward and forward before the sprint. Excellent reliability for 20-m sprint time has been reported by Lockie et al. (29), with an intraclass correlation coefficient (ICC) of 0.96, smallest worthwhile change of 0.06 seconds, and smallest worthwhile change of 0.09 seconds.

**TABLE 2.** Changes in pace bowling skill, approach speed, acceleration speed, and 1RM pull-up strength within the CRT group.*

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Standardized difference (post-pre)</th>
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<tbody>
<tr>
<td></td>
<td>n Mean</td>
<td>SD Mean</td>
<td>SD Mean</td>
</tr>
<tr>
<td>Peak ball release speed (m·s⁻¹)</td>
<td>5 32.6</td>
<td>1.7</td>
<td>33.8</td>
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<tr>
<td>Mean ball release speed (m·s⁻¹)</td>
<td>6 31.6</td>
<td>1.9</td>
<td>32.3</td>
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<td>Variability of ball release speed (m·s⁻¹)</td>
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<td>Mean radial error (cm)</td>
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<tr>
<td>Bivariate variable error (cm)</td>
<td>6 40.9</td>
<td>7.5</td>
<td>48.7</td>
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<td>Delivery RPE (% of 100)</td>
<td>6 91.9</td>
<td>5.7</td>
<td>92.7</td>
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<tr>
<td>Approach speed (m·s⁻¹)</td>
<td>6 5.35</td>
<td>0.39</td>
<td>5.38</td>
</tr>
<tr>
<td>20-m sprint time (s)</td>
<td>5 3.43</td>
<td>0.09</td>
<td>3.51</td>
</tr>
<tr>
<td>1RM pull-up (kg)</td>
<td>2 80.6</td>
<td>5.8</td>
<td>86.4</td>
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*1RM = 1 repetition maximum; CRT = combined resistance training; CL = confidence limit; RPE = rating of perceived exertion.

One Repetition Maximum Pull-up Assessment. Ten minutes after the 20-m sprint test, a 1RM pull-up test was conducted. This test was included as a measure of upper-body pulling strength and assesses the latissimus dorsi muscle (53), which is strongly activated during the propulsive phase of baseball pitching (25). The test was conducted in a Smith machine, where the bar could be adjusted and fixed to a height that subjects could just reach when standing. Subjects adopted a pronated but slightly wider than shoulder-width grip on the Smith machine bar. Without jumping, subjects were required to pull their body upward so that their chin cleared the bar. On lowering, they had to fully extend their arms. A warm-up set of 3 repetitions was initially performed at the subjects’ body mass. Some subjects could only achieve one repetition at their body mass, whereas others failed to complete one repetition. Subjects who could not complete the test did not receive a score. Nevertheless, for those with sufficient strength, 2 repetitions were conducted from each set afterward, with a safe but gradual increase in load until “technical failure” occurred on the second repetition. Technical failure was evident in this test if subjects could not complete full range of motion (i.e., raise their chin above
Load was increased through a weight-belt and chain that accommodated weight plates. A 4-minute passive rest was adopted between test sets to allow sufficient time for central nervous system recovery. Encouragement was provided each test set. The 1RM load was usually determined within 5 test sets, which minimized the effects of fatigue on test performance. The test-retest reliability of the 1RM pull-up was not established; however, Coyne et al. (8) reported the ICC to be 0.99 following a similar protocol to this investigation.

Bowling Training. Both groups undertook the general warm-up and the first 15 deliveries from the specific bowling warm-up to prepare for each training session. Bowling was completed first in each training session. The CRT group bowled the first third of deliveries with a 300-g ball, the next third with a 250-g ball, and the final third with a 156-g ball. The reason for this order was that the heavier balls would be expected to tax the neuromuscular system more than the standard balls, and so, the recommendation to place exercises with greater neurological demand first within the program was adopted (1). The 300 and 250-g balls were selected in line with the recommendations by Wickington and Linthorne (47) that heavier balls up to 400 g could provide a more sufficient training stimulus, by reducing the relative speed of ball release by more than 5%. Furthermore, only heavier implements were used in this investigation, as it has been recommended that these should be trained with first to develop the functional strength before throwing lighter implements where the speed of movement is emphasized (16). The ratio of heavy-ball to standard-ball bowling was set to 2:1 for the CRT group based off previous recommendations (35).

For both groups, the first two-thirds of bowling within the session was performed from a short 5-step run-up, with an instruction to bowl at "maximal effort." The target sheet was removed, which meant bowlers delivered only to a high-jump mat, and so were only focusing on bowling with maximal effort each delivery. A focus on bowling speed in this block was justified, as Feros et al. (19) observed that 8 of their 13 subjects of similar standard displayed no statistically significant relationship between ball release speed and radial error. The shortened approach was selected to emphasize greater upper-body/trunk contribution to bowling speed, by removing some of the momentum generated from the run-up, as run-up velocity is known to strongly relate to bowling speed (15). The final third of balls were delivered from a full run-up, with the instruction to bowl at "match speed and accuracy." The target sheet was returned to its original position, and for each delivery, bowlers were instructed on which target to aim for. Each delivery was bowled on a 30-second cycle, monitored by the "LabTimer" application.

Acceleration Speed Training. Twenty-meter sprints were performed after a 10-minute passive recovery after bowling training. Subjects in the CRT group were weighed, and vests (20 kg Power Vest; Iron Edge, Melbourne, Australia) were adjusted to +20 and +15% of body mass. Afterward, the specific sprint warm-up was conducted. The CRT group performed the first third, second third, and final third of their 20-m sprints with a +20% vest, +15% vest, and no vest, respectively. The unresisted sprints were scheduled at the end to allow subjects to benefit from any elicited potentiation (3), which would be expected to enhance the training stimulus. The TCT group sprinted unresisted (i.e., no vest). Subjects were instructed to perform each sprint with "maximal effort." A 2-minute walking recovery between sprints was adopted. Both the +20 and +15% vest loads were chosen for the CRT group, as Cronin et al. (10) observed that both loads were capable of altering sprint kinematics to make the sprinter more "upright," resulting in a possible greater eccentric load during the braking phase of ground contact (10). Although this was a suggested adaptation to vest training, the improved braking ability would be beneficial for cricket pace bowlers, as the ability to rapidly
decelerate the center of mass from front-foot contact to ball release is related to faster ball release speeds (17), and so is a more extended front-leg at the moment of ball release (30,49,50).

Chin-up and Pull-up Training. In each training session, the CRT group completed 3 sets of 5 maximum chin-ups or pull-ups (body mass resistance only) with a 3-minute recovery between sets. These were performed after a 10-minute passive recovery from the acceleration speed training. In weeks 1–3 of the program, chin-ups were completed with hands positioned shoulder-width apart (with supinated forearms). Then, in weeks 4–6, subjects performed pull-ups with hands positioned shoulder-width apart (with pronated forearms). In the final 2 weeks, subjects completed pull-ups with hands positioned ~25 cm from either shoulder (i.e., wide grip with pronated forearms). The change in grip and hand position was used to progress the difficulty of the exercise as well as to provide variety to the training. Subjects who reached technical failure before the fifth repetition were provided assistance from a spotter during the concentric phase of the lift only, to achieve the minimum of 5 repetitions, but no more were performed for the set. Therefore, each subject completed a minimum of 5 repetitions per set.

Statistical Analyses
Statistical power for the study was conducted a priori in G*Power (Version 3.1.92; Universität Kiel, Germany) through the repeated-measures analysis of variance, within-between factors (the F test). To detect a small effect size (f) of 0.1 for mean ball release speed, a minimum of 12 subjects were required for this study (6 per group). The alpha error probability was set to 0.05, power (1-β error probability) set to 0.80, 2 groups with 2 measurements (pre-test and post-test), a correlation among repeated measures of 0.98 (ICC of mean ball release speed, Table 1), and a nonsphericity correction of 1.

All statistical analyses and calculations were performed using IBM SPSS Statistics (25.0.0.1; IMB Corp., Armonk, NY, USA) or Microsoft Excel (version 2016; Microsoft Corp.). Descriptive statistics were expressed as mean (±SD). All data were first checked for normality (the Shapiro-Wilk test), kurtosis, and skewness with respect to each group. All data were normally distributed.

As previously mentioned, the test-retest reliability of each pace bowling skill measure and approach speed was examined in a separate but similar sample of pace bowlers. This comprised two 8-over bowling tests separated by 1 week (19). The data from the first 4 overs of the 2 tests were extracted and entered into a purpose-made Microsoft Excel spreadsheet (27), where the SEM, log-transformed coefficient of variation, and ICC (model 2,k) were calculated as measures of test-retest reliability (46). The smallest worthwhile change represented the sensitivity of each measure and was calculated by multiplying the pooled between-subject SD from both reliability trials (SEM by 0.2).

An independent samples t-test was conducted to ascertain any between-group differences at the pre-test period. Afterward, data were analyzed through a 2-way repeated-measures analysis of variance (mixed design). Two levels corresponding to the training groups (i.e., TCT and CRT) were specified as the between-subjects factor (GROUP). The within-subjects factor (TIME) represented the pre-test and post-test measures. Sidak post hoc analysis was used not only to perform multiple comparisons between groups and time points but also to improve statistical power for the multiple comparisons.

Effect sizes from the repeated-measures analysis of variance were converted to a Cohen’s d statistic (7). The precision of mean differences was expressed with 95% confidence limits (95% CLs). The 95% CLs were constructed around the mean differences to express the range of uncertainty of the interval containing the true parameter value. Qualitative descriptors of standardized (Cohen’s d) effect sizes were assessed using these criteria: trivial <0.2, small 0.2–0.49, moderate 0.5–0.79, and large >0.8 (7). Effects with 95% CLs overlapping the thresholds for small positive and
small negative effects (i.e., exceeding 0.2 of the 95% CLs on both sides of zero) were defined as "unclear." A "clear" effect size was defined as the mean of the 95% CL being ≥0.2 and not exceeding a trivial effect size on the other side of zero (4). An alpha level of ≤0.05 was chosen to constitute statistical significance for all analyses.

**RESULTS**

The 1-way analysis of variance revealed no significant differences in all variables between groups at the pre-test period (p > 0.05). The 2-way repeated-measures analysis of variance did not reveal any significant GROUP × TIME interactions (p > 0.05).

The CRT group demonstrated a "clear moderate" change in peak ball release speed (mean ±95% CL: 1.2 ± 1.5 m·s⁻¹, ρ = 0.119, d = 0.66 ± 0.83, Figures 1 and 2, Table 2), a "clear large" change in mean radial error (mean ±95% CL: 7.1 ± 6.5 cm, ρ = 0.035, d = 1.13, Figures 1 and 3, Table 2), and a "clear large" change in bivariate variable error (mean ±95% CL: 72 ± 78 cm, ρ = 0.072, d = 1.08, Figures 1 and 3, Table 2). The TCI group exhibited "unclear" changes across all pace bowling skill measures (Figures 1–4, Table 2). Both groups displayed "unclear" changes in approach speed, 20-m sprint time, and 1RM pull-up strength (Figure 1, Tables 2 and 3).

**DISCUSSION**

There were no significant GROUP × TIME interactions identified in this investigation (p > 0.05), indicating that the CRT program was no different to the TCT program with respect to measures of pace bowling skill, approach speed, acceleration speed, and 1RM pull-up strength. These findings in part may be due to the smaller sample size (n = 6) in each group, which reduced the statistical power for other measures apart from mean ball release speed.

After taking into account the limitation of reduced statistical power, the CRT group demonstrated a "clear" improvement in peak ball release speed of 1.2 ± 1.5 m·s⁻¹ (mean ±95% CLs), which was marginally better than the improvements observed in previous studies trialling modified-implement programs in cricket pace bowling (35,47). The observed improvement in peak ball release speed may partly be attributable to the implementation of the 250 and 300-g balls, which were markedly heavier than previously trialled (35,47). Petersen et al. (35) prescribed a gradual increase and decrease in ball masses throughout the 10-week training intervention, with balls ranging from 84–116% of standard mass. By contrast, Wickington and Linthorne (47) proposed changes in ball release speed of at least ±5% might be necessary for a modified-implement training program to be effective in developing bowling speed. To achieve this arbitrary change in cricket pace bowling, the ball mass must be significantly heavier or lighter than the recommended 20%. Wickington and Linthorne (47) reported that as ball mass increases by 100 g, ball release speed decreases at a rate of ~1.1 m·s⁻¹. When their model is applied to this study, the 250 and 300-g balls would have decreased bowling speed by 1.0 m·s⁻¹ (3.2%) and 1.5 m·s⁻¹ (5.1%), respectively; possibly providing a sufficient training stimulus, on the assumption that a −5% reduction in ball release speed is appropriate to induce favorable adaptations to this performance measure.

**TABLE 3. Changes in pace bowling skill, approach speed, acceleration speed, and 1RM pull-up strength within the TCT group.**

<table>
<thead>
<tr>
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<th>Standardized difference (post-pre)</th>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Peak ball release speed (m·s⁻¹)</td>
<td>6</td>
<td>31.7</td>
<td>2.7</td>
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<tr>
<td>Mean ball release speed (m·s⁻¹)</td>
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<td>Bivariate variable error (cm)</td>
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<td>Delivery RPE (% of 100)</td>
<td>6</td>
<td>90.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Approach speed (m·s⁻¹)</td>
<td>6</td>
<td>5.59</td>
<td>0.65</td>
</tr>
<tr>
<td>20-m sprint time (s)</td>
<td>6</td>
<td>3.28</td>
<td>0.12</td>
</tr>
<tr>
<td>1RM pull-up (kg)</td>
<td>5</td>
<td>91.9</td>
<td>20.5</td>
</tr>
</tbody>
</table>

*1RM = 1 repetition maximum; TCT = traditional cricket training; CL = confidence limit; RPE = rating of perceived exertion.
Given the “unclear” change in 1RM pull-up strength of 5.8 ± 7.4 kg (mean ± 95% CL) within the CRT group, it is unlikely that chin-up and pull-up training contributed to the changes observed in peak ball release speed. This result is likely to be masked by the fact that only 2 subjects in the CRT group were able to complete the 1RM pull-up test due to poor relative strength across the group. Based off the previously reported correlation between 1RM pull-up strength and peak ball release speed (22), we expected that improvements in 1RM pull-up strength would display some degree of positive transfer to peak ball release speed. Chin-up and pull-up training was included to develop 1RM pull-up strength, as both the chin-up and pull-up exercises target similar muscles to those involved in cricket pace bowling (41).

In view of the “unclear” differences in approach speed and 20-m sprint time in either group, unsuristed sprinting or a combination of vest and unsuristed sprinting did not seem to be effective in improving these qualities, and therefore was unlikely to transfer to the improvements in peak ball release speed observed for the CRT group. Recently, Rey et al. (39) observed that vest sprinting twice per week over 6 weeks was just as effective (but not more effective) than unsuristed sprinting at enhancing 10-m sprint time (9.4% vs. 10.9%, respectively) and 30-m sprint time (6.0% vs. 5.1%, respectively) in soccer athletes. Although the prescribed vest load (18.9% ± 2.1%) was similar to this investigation, the weekly sprint volume was marginally less (240–560-m vs. 360–600-m). Furthermore, Rey et al. (39) prescribed multiple sets of 20-m sprints with a 5-minute recovery between sets and 2-minute recovery between sprints, whereas this investigation prescribed one set of multiple 20-m sprints with a 2-minute recovery between sprints. This may have meant the subjects in this study were sprinting in a fatigued state, especially because acceleration speed training followed bowling training. If such fatigue accumulated over a number of training sessions, then the excessive training stimulus may have resulted in the subjects overreaching, and therefore not expressing favorable adaptations to acceleration speed. We prescribed sprint training after bowling training to reduce the number of training sessions required for subjects to attend (and thus negate subject attrition), and because professional fast bowlers display a high volume of sprinting (>5 m·s⁻¹) in 1-day cricket (344 ± 93-m per hour) and first-class cricket (334 ± 134-m per hour) (34).

Despite the favorable adaptations of bowling with heavier modified implements, a trade-off was evident due to the “clear moderate” increases in radial error (i.e., bowling accuracy) and bivariate variable error (i.e., consistency of bowling accuracy) observed within the CRT group. These detrimental effects indicated a negative transfer from heavy-ball bowling to standard-ball bowling. Negative transfer occurs when 2 performance situations are similar, but movement characteristics differ (31,40). Although speculative, the negative transfer may be due to a change in neuromuscular coordination (16) and the relatively large transitions in ball mass within each training session. In this study, bowlers in the CRT group transitioned to different ball masses on 3 occasions, (a) 156-g ball to 300-g ball (92% increase), (b) 300-g ball to 250-g ball (20% decrease), and (c) 250-g ball to 156-g ball (60% decrease). Such large fluctuations in ball mass may have been more noticeable to the bowler, through possible changes in the technique. Subjects in this study informally but frequently reported that the standard ball “felt lighter” to bowl with immediately after bowling with the heavier balls. Morimoto et al. (33) also reported similar comments with respect to pitching heavier baseballs to standard baseballs. Cratty and Hutton (9) described this phenomenon as “kinesthetic illusion,” where subjects “feel” they are moving faster after the transition from heavier to lighter loads, but there is little influence on actual movement speed. Nevertheless, the apparent change in “feel” on transition between balls may have interfered with the bowler releasing the ball from a consistent angle. Application of the 2-dimensional aerodynamic model of cricket ball flight (47) indicates that the 250 and 300-g ball would increase ball release angle by ~0.5 and ~0.7°, respectively. This would correspond to a reduced delivery length of ~0.4 and ~0.6-m, providing the bowler was attempting to land the ball on a “good length.”

It may be for these aforementioned reasons that others have recommended that modified implements should closely match the mass of the standard implement as to maintain the normal neurological recruitment patterning of the limb (11,16,45). DeRenne et al. (13) prescribed transitions of ball mass of ±5–20% throughout a 10-week modified-implement program and observed a 1.7 ± 1.1 m·s⁻¹ improvement in throwing velocity, despite no measure of throwing accuracy. Morimoto et al. (33) observed no significant differences in throwing accuracy with a standard ball following modified-implement warm-ups of 6–18 throws with ±10% balls ($p > 0.05$), although throwing velocity was immediately potentiated after 6–18 throws with a 10% lighter ball. Interestingly, Petersen et al. (35) adopted a similar approach to DeRenne et al. (13) with cricket pace bowlers and reported a 1.1 m·s⁻¹ improvement in ball release speed but a 7% decrease in bowling accuracy. By contrast, Wickington and Linthorne (47) observed a 0.9 m·s⁻¹ enhancement in bowling speed but a “substantially beneficial” increase in bowling accuracy after 8 weeks of modified-implement training with balls of 46–157% of standard mass. The substantially beneficial increase in bowling accuracy was arguably influenced by 2 bowlers, whereas the other 3 bowlers displayed “unclear” changes (47). Furthermore, it is important to note that Petersen et al. (35) and Wickington and Linthorne (47) adopted coach friendly approaches to the assessment and scoring of bowling accuracy, which are not as precise as estimating the radial error from digitized footage (21). With this limitation in consideration, it appears that modified-implement training transfers positively to peak ball release speed through possible
development of arm strength and power (35), but transfers negatively toward radial error and bivariate variable error because of the biomechanical similarities.

An alternative approach to developing ball release speed without potentially compromising measures of bowling accuracy could be to use only “general” and “special” resistance exercises that are less biomechanically similar to the cricket pace bowling motion. Although there is no published study to date that has trialled the efficacy of traditional strength and power exercises on cricket pace bowling skill, there is evidence that developing these physical capacities through “general” and “special” resistance exercises can significantly develop throwing velocity in baseball (14) and handball (26,38). Furthermore, Raeder et al. (38) observed no statistically significant difference in throwing precision after 6 weeks of medicine ball training (a special resistance exercise program). Therefore, these types of resistance exercises may be more effective for developing overall pace bowling skill when compared with bowling only with a standard ball, as the latter does not appear to develop ball release speed or bowling accuracy in a short-term block of 8–10 weeks (35,47).

It is important to note that this study comprised several limitations. The small sample size in this investigation resulted from recruiting a specific population (i.e., pace bowlers), attrition rate, motivation, and injuries external to this research. This meant that a majority of variables (apart from mean ball release speed) were underpowered in statistical analysis. A high-performance sample would have been ideal to recruit because it is desirable to apply the results of this investigation to elite fast bowlers. However, this sample is difficult to recruit given organizational and player constraints. A high-performance sample would be expected to display greater strength and power, and obviously superior bowling skill compared with the club-standard cohort in this investigation. There were multiple differences in the design of the 2 training programs, with many independent variables. For example, the CRT group bowled with heavier and standard implements, conducted vest and resisted sprinting, and performed chin-up and pull-up training, whereas the TCT group bowled with a standard ball and sprinted resisted only. Although this particular design can inform coaches of how effective a particular program is for improving sports performance, its limitation is the inability to quantify what contributed to the change in performance. Absolute ball masses were prescribed in the CRT program, which may not have taken into consideration the strength capacity and anthropometric profile of the subjects in this investigation. One possible solution could have been to prescribe ball mass based on the loads that induce a ±5% change in ball release speed for each subject (47). This could be achieved by trialling a range of weighted deliveries and tracking the ball release speed of each delivery in relation to that of a standard ball. However, it is not known whether the ±5% change in ball release speed is an optimal training stimulus for the improvement of pace bowling skill. Finally, a delimitation to this study was that the CRT program was designed solely off the research conducted in cricket pace bowling to date; it is plausible that various resistance exercises trialled in other throwing-related sports research (e.g., baseball, javelin, and handball) may have resulted in positive transfer to cricket pace bowling skill in this study.

**PRACTICAL APPLICATIONS**

Strength and conditioning coaches typically use a range of resistance exercises that can be classified as general, special, or specific to enhance sporting performance (14). Bowling with 250 and 300-g balls is a specific type of exercise that appears to positively transfer to peak ball release speed; however, it negatively transfers to measures of bowling accuracy. Given the equal importance of both speed and accuracy in cricket pace bowling, we cannot recommend the prescription of heavy-ball bowling to improve all-round pace bowling skill in club-standard cricketers.

“General” and “special” resistance exercises that target the development of muscular strength and power may be more appropriate for the development of all-round pace bowling skill as opposed to “specific” resistance exercises (e.g., heavier ball bowling). These traditional-type exercises would allow the bowler to better develop the underlying physical capacities required to enhance skill and performance. Furthermore, “general” and “special” resistance exercises would expose the bowler to higher training loads during the cricket pre-season, which would assist in their ability to tolerate such load during the competitive season.

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