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The Effects of A 14-Week Physical Preparation Programme on Developing Adolescent Seam Bowlers in Cricket

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ABSTRACT

From a physical demand point of view, fast bowling is reported to be the most demanding position in cricket. Unsurprisingly, physical preparation has been shown to enhance performance and reduce injury risk in adult seam bowlers. However, limited research has been conducted into the effects of physical preparation in youth developing seam bowlers.

Therefore,the purpose of this study was to determine the effectiveness of a 14-week physical preparation programme on the developing seam bowler.

Six developing academy-level seam bowlers (18.1 ± 1.1 years) completed a 14-week periodised bowling-specific programme. Pre/post tests across various physical qualities (strength, power, muscular endurance, speed and aerobic capacity) and bowling performance (upper arm angular velocity) were recorded. Changes from pre-post testing were measured using a paired sample t-test ($p \leq 0.01$) and effect sizes.

Post 14-week intervention, group relative changes showed improvement in strength (+8%), power (+2%), muscular endurance (+45%), speed (-6%) and aerobic capacity (+3). Within participant group there was no significant difference ($p = 0.77$) in upper arm angular velocity.

Positive improvements in all physical qualities were recorded post intervention. Interestingly, this did not translate into an increase in upper arm angular velocity. Future research should consider the benefits of mixed-methods research approach, where the technical and physical characteristics are closely aligned within developmental programmes, to enhance performance and reduce injury in this population.

Keywords: bowling performance, strength and conditioning, physical performance, youth

INTRODUCTION

Cricket is a game played with a bat and ball, between two opposing teams of eleven players, and across different formats consisting of Twenty20 (T20), one day, multi-day and now the Hundred. Although the formats differ in terms of physical demands and time constraints, the skill requirements remain consistent. There are several roles within a cricket team, namely, batsman, seam bowler (fast/medium), spin bowler, and wicket keeper, with players often fulfilling several of these roles. Seam bowling has been shown to be the most physically demanding when compared to the other roles within the team (1). This is due to the total distance covered during games, intensity of sprints and repeated high ground reaction forces

experienced during their bowling action (1,2).
Seam Bowlers' (SBs) main aim is to dismiss opposing batters, as well as limit the number of runs scored during the game. This can be achieved by varying the length and speed of the delivery during their run-up before an explosive leap into the delivery stride (3). One strategy that SBs use to achieve these goals is to increase ball release speed (BRS), which refers to the velocity of the ball once it has left the bowler's hand. Increases in BRS can be achieved by increasing run-up speed, developing muscular strength, and increasing anaerobic abilities (3,12). This will allow for a repeated increased transition of force from the lower body up through the trunk and onto the upper body, thus maximising BRS (12,20).

During the delivery stride the SB experiences high vertical and horizontal ground reaction forces (GRF) up to 9x their bodyweight (5). In addition, the upper body experiences instantaneous lateral trunk flexion and hyperextension into the ball release phase (4). These movement patterns during each delivery occur in every game and/or training session and are interspersed by phases of low and high intensity running/walking as well as skills such as throwing, diving, and jumping.

Strength and conditioning is used to physically prepare players, enhance performance, and reduce injury risk through gym and field-based exercise programming (2, 15, 18, 20). A review by Johnstone and colleagues (22) identified several areas for consideration when physically preparing SBs including the need for SBs to have a well-developed anaerobic metabolic system that replicates match demands and have a progressive periodised strength programme targeting the muscle groups used in bowling. This allows bowlers to better withstand the repetitive muscular work during the bowling action. For example, during the bowling action the humerus circumducts using the latissimus dorsi and pectoralis major and the deltoid muscles with the biceps brachii and rotator cuff muscles stabilising the elbow, and glenohumeral joint (31). An appropriately designed physical preparation programme that targets these areas of the upper arm will assist in resisting glenohumeral distraction and control the elbow during elbow extension. This should, in theory, increase the bowler's ability to withstand the repetitive nature of their bowling action. Additionally, lower-body eccentric strength is a key trait from both a technical standpoint (maintaining an extended front leg) and physically being able to cope with the fatiguing mechanisms associated with fast bowling (22). Therefore, the strength and conditioning coach should include exercises in their physical preparation programmes that target the muscles of the upper body that are active during the bowling action (pectoralis major, latissimus dorsi, biceps brachii and rotator cuffs) and the lower body muscles during front and back foot contact (quadriceps, hamstrings, gastrocnemius, soleus, and gluteus), as well as implementing lower body eccentric exercises at the appropriate stage of programme. This should assist the seam bowler from a technical standpoint (maintenance of an extended front knee) and physically (withstanding fatigue) (20,22).

To date, research in this area has focussed on adult cricketers leading to a lack of data relating to the physiological and physical demands of fast bowling in youth populations. Future research within youth cricketing populations would provide practitioners with evidence-informed guidelines when physically preparing youth populations. Therefore, the purpose of this study was to determine the effects of a 14-week physical preparation programme on developing adolescent seam bowlers.

METHODS

Participants

Six national level academy male adolescent developing seam bowlers were recruited for the study. Participants' descriptive characteristics are presented in Table 1. The 14-week training programme was conducted during pre-season lasting from November 2021-March 2022. All six participants were right-handed. The University Ethics committee approved all procedures. A study brief (Appendix A) and informed consent (Appendix B) was provided to each participant and was signed by themselves and or parent/guardian prior to the commencement of the study.

Training Programme

Participants followed the same strength and conditioning programme (SCP) which consisted of two gym-based sessions and one conditioning session per week on non-consecutive days during a total of 14 weeks (28 gym-based sessions and 14 conditioning-based sessions) (Appendix C). With overall attendance for gym-based sessions was 89.2 percent with conditioning sessions having a 100 percent attendance (Appendix D). The SCP followed a multi-targeted block periodisation approach with the view of developing multiple physical and physiolog-

Table 1. Descriptive characteristics of participants.

Bowlers (n = 6)	Mean ± SD
Age (years)	18.10 ± 1.06
Height (cm)	183.16 ± 3.65
Body Mass (kg)	75.83 ± 4.87
Resistance training age (years)	1.10 ± 0.71

**SD = standard deviation; cm = centimetres; kg = kilograms*

ical adaptations such as muscular strength, power, aerobic endurance and anaerobic capacity (7,20), To achieve these physical and physiological adaptations the difficulty and intensity of the exercises were progressed after each 4-week mesocycle which was calculated using each participant's repetition maximum. All players had a one-week de-load at the end of the final block of training. This approach has been shown to develop muscular strength via a combination of morphological and neural factors (7). The programme included exercises recommended for targeting and developing lower (back squat, romanian deadlift and deadlift) and upper-body strength (military press and barbell row) (24,25), core strength variations (e.g., front and side plank) (32) and eccentric capacity (bilateral box jumps) (15). All selected exercises were based on previous research (3,24,20,25,7) and current strength and conditioning practices within high performance cricket (Weldon, 2020). All training sessions were supervised by the researcher who is an accredited strength and conditioning coach and first aid trained. All participants completed a standardised warm up prior to all sessions which included whole-body mobility exercises along with landing and jumping exercises which targeted eccentric capacity. The full details of the SCP can be accessed in appendix D.

Measures

Testing variables were lower body counter-movement jump (CMJ), 20-m sprint test, upper body strength test (bench press & bent over row), lower body strength test (hex-bar deadlift), upper body muscular endurance (horizontal pull), aerobic capacity (Yo-Yo intermittent recovery Level 1 test) and upper arm angular velocity. All participants were tested at the same time of day pre and post 14-week intervention.

CMJ was conducted using the OptoJump (Microgate, Bolazano, Italy) (8). Prior to testing, participants performed a standardised warm up prior to the test lasting five minutes. Participants were instructed to stand between the two sticks and perform a CMJ maximally whilst maintaining extend knees during flight. Each participant had three attempts with best attempt being recorded as the score. Each attempt was separated by 2 minutes rest. After five minutes of passive recovery participants performed an additional standardised warm up to ensure they warmed up to a maximal sprint speed safely and reduce the risk of injury. The warm-up consisted of 5 x 20m sprints from a stationary start on every minute, at 60, 70, 80, 90 and 95% of perceived effort, with the walk back acting as the recovery prior to the 20-m sprint test (8). Two timing gates (Microgate, Bolazano, Italy) were placed next to cones (A&B) 20 meters apart which recorded each participant's time. Participants readied themselves 0.3m behind cone A in a two-point split stance and were instructed to run maximally to cone B on the count of three (8). Three trials were conducted by each participant with the fastest used for data analysis.

For upper and lower body strength test a three-repetition maximum (3RM) protocol was used (8). Each participant warmed up with a load that allowed them to 5-10 repetitions followed by a one-minute rest. An estimated load was selected that allowed each participant to complete 3-5 reps by adding 5-10 % for upper-body exercises (bench press) and 10-20% for lower-body (back squat and deadlift) on to the weight of previous load, followed by a two-minute rest then completing a near maximal load for three reps by adding 5-10% (upper-body) or 10-20% (lower-body) on to the weight of previous load. Each participant then had a 2–4-minute rest before following the process of the previous step to establish their 3RM. Final 3RM was confirmed within five testing sets.

The horizontal pull test was used to measure the participant's upper body strength and endurance abilities (9). A weightlifting barbell was placed in the squat rack at a height when the participant grasped the bar their arms were fully extended, and their body was off the floor. Participants were instructed to grasp the knarley part of the bar slightly wider than shoulder-width apart. Their feet were flat on the floor with their knees flexed at a 90° angle. Each participant then extended their hips and elbows were fully straight before pulling their body to the bar in-line with their nipple line then return to the start position. This sequence was repeated until they could not complete the sequence as described above, with repetitions recorded for data analysis.

The Yo-Yo intermittent recovery Level 1 test was performed 72 hours after the previous test (8). Each participant performed a standardised warm up prior to the test. A 20-meter distance, with an additional 5-meter distance, was measured out behind the starting line on indoor sports surface. Participants were instructed to toe the starting line in a two-point stance and on the audio signal (beep) run towards the to the turning line and then back to the starting line, ensuring they are on time with the next sound (beep). Once passed the starting line, participants jogged to the 5-meter mark then turn back to the start line in preparation for the next sound. Warnings were given for inability to complete a shuttle, false starts, with two warnings leading to elimination. After completion of test each participant distances were individualised and set based of their level, as seen in a previous study by Herriddge and colleagues (10).

Ball release speed (BRS) has previously been shown to decrease batsmen's decision-making time and increase opportunities to take wickets (3). Participants were fitted with 17 MTx inertial measurement units (IMU's) (XSENS technology, Enschede, The Netherlands) using an MVN Lycra suit (XSENS technology, Enschede, The Netherlands), with a sample frequency of 120 Hz, prior to each performing a self-prescribed warm up. IMU sensors were located on participants pelvis, sternum, head and left and right shoulders, upper arms, forearms, hands, upper legs, lower legs, and feet. Once fitted, body dimension measures were recorded in the MVN software with suit calibration posture recorded using the N-pose (26,12). To derive BRS, IMU sensor data derived from the upper arm for each delivery was used to determine peak upper arm angular velocity. Previous research has shown the XSENS motion analysis system to be a valid and reliable means of measuring angular velocities (27,12).

As previously outlined by Faber and colleagues (26) the MVN software identifies calibration quality in one of four levels (good, acceptable, fair and poor). Only calibration files that achieved a level of good were used in order to maintain an acceptable quality of recordings.

The pre intervention bowling test took place seven days after the physical test and was conducted over a 6-day period with the post testing intervention bowling test conducted over a 17-day period due to the availability of testing facilities. Once warmed up each participant completed a 6 over spell, comprising of 6 maximum effort deliveries of varying lengths (short, 7-10m; good, 4-7m and full 0-4m from the batting stumps) in a randomised order to simulate various delivery lengths within match play (3). The number of over were selected based on the International Cricket Council's bowling recommendations for this population. Laboratory dimensions allowed for each participant to use sue their normal run up and follow through. A four-minute active recovery was used between each over, to simulate the demands of match-play. All participants used a white Duke (156g) cricket ball and their own bowling shoes during testing.

Statistical procedure

Descriptive statistics of physical qualities (Table 2) were presented as mean ± standard deviations to describe each variable. Mean difference and 99% confidence limits (CL) were also established between pre- and post-test measures. Paired sampled t-test was used to establish changes between pre- and post-testing measures. In order to reduce the risk of a Type 1 error, the criterion for statistical significance was set at $p \leq 0.01$. Statistical tests for physical qualities were conducted using the Jamovi software package (Version 3.2.3). Owing to small sample sizes Hedges g effect sizes were applied for pre- and post testing comparison. The effect magnitude was assessed using the following scale: less than 0.2 was deemed a trivial effect; 0.2 to 0.49 a small effect; 0.5 to 0.79 a medium effect; and more than 0.8 a large effect (13). Statistical tests for upper arm peak angular velocity were conducted using Graph Pad version 9.4.1(Prism - GraphPad, n.d.), with individual results of upper arm angular velocity presented for each participant in Table 3. A Mixed Model 2-Way ANOVA was used to establish changes pre and post testing with alpha level set at 0.01 (Table 3).

RESULTS

The data followed a normal distribution ($p \leq 0.01$). After the training, lower-body power (CMJ) showed a non-significant increase ($p = 0.47$) by 2% from pre (38.7 ± 3.56 cm) to post (39.31 ± 2.88 cm), with a trivial ES (0.32) (Table 2). Post 20m sprint time also improved significantly ($p = 0.00$), decreasing by 6%

from pre (3.12 ± 0.05 sec) to post (2.93 ± 0.08 sec), with large ES (-4.71) (Table 2). The post-times were faster than the minimum ICCHPP standards (3.03 sec). Yo-Yo IR Level 1 increased non-significantly (*p* = 0.42) by 3% from pre (level 18.18 ± 1.92) to post (level 18.65 ± 2.44), with a trivial ES (0.36) (Table 2). Lower body strength (hex bar deadlift) improved significantly (*p* = 0.01) by 28% from pre (116.5 ± 17.86 kg) to post (148.66 ± 29.02 kg), with a large ES (1.86) (Table 2). Upper body strength (bench press) enhanced significantly (p = 0.001) by 23% from pre (61.66 ±14.02 kg) to post (75.83 ± 13.19 kg), with a large ES (3.76) (Table 2), higher than international SBs' score for 6RM bench press. Bent over row (p = 0.01) and horizontal pull up (*p* = 0.01) also improved significantly by 28% and 45%, respectively,

Table 2. Pre–post testing (mean ± standard deviation) and difference (mean difference ± 99%) results for counter-movement jump (CMJ), 20m speed (20m), Yo-Yo level-1, hex-bar deadlift, bench press, bent over row and horizontal pull up in adolescent developing seam bowlers (n = 6).

Fitness test	Pre-testing (Mean ± SD)	Post-testing (Mean ± SD)	Mean difference	Percentage change	*P* value	ES
CMJ (cm)	38.70 ± 3.56	39.31 ± 2.88	0.62	2	0.47	0.32
20m (sec)	3.12 ± 0.05	2.93 ± 0.08	0.20	-6	0.00	- 4.71
Yo-Yo IR Level 1 (Lvl)	18.10 ± 1.92	18.65 ± 2.44	0.47	3	0.42	0.36
Hex Bar Deadlift (kg)	116.50 ± 17.86	148.66 ± 29.02	32.2	28	0.01	1.86
Bench Press (kg)	61.66 ±14.02	75.83 ± 13.19	14.2	23	0.001	3.76
Bent Over Row (kg)	63.33 ± 12.11	81.33 ± 10.23	18.0	28	0.01	1.63
Horizontal Pull Up (reps)	15.50 ± 2.07	22.50 ± 2.73	7.0	45	0.01	1.96

**CM = centimetres; sec = seconds; Lvl = level; kg = kilograms; reps = repetitions*

Table 3. Pre and post testing results from bowling upper arm peak angular velocity in adolescent seam bowlers (n = 6).

	PRE				POST			
	Pre O1B1	**Pre O1B6**	**Pre O6B1**	**Pre O6B6**	**Post O1B1**	**Post O1B6**	**Post O6B1**	**Post O6B6**
Participant 1	902.7	856.3	1092.6	728.3	675	613.2	-	636
Participant 2	-	556.5	682.1	872.1	1132.9	906.1	1170	945.2
Participant 3	875.1	1336	911.5	1081.2	753.5	628.3	859.3	713.7
Participant 4	782	668.2	774.4	842.5	575.3	613.2	675.1	588.9
Participant 6	529.6	552.8	679	562.5	592.2	628.8	660.9	652.7
Mean	772.35	793.96	827.92	817.32	745.78	677.92	841.325	707.3
SD	169.87	327.13	175.60	191.13	227.81	127.79	237.02	140.29

**Pre O1B1 = over 1, ball 1; Pre O1B6 = over 1, ball 6; Pre O6B1 = over 6, ball 1; Pre O6B6 = over 6, ball 6; Post O1B1 = over 1 ball1; Post O1B6 = over, ball 6; Post O6B1 = over 6, ball 1; Post O6B6 = over 6, ball 6.*

DISCUSSION

The aim of this study was to investigate the effects of a 14-week physical preparation programme on developing adolescent seam bowlers. The main findings post 14-week intervention showed group relative changes across all physical qualities with improvements in strength, hex-bar deadlift (+28%, *p* = 0.01), bench press (+23%, <.001) and bent over row (+28, 0.01), as well as improvements in power (+2%, *p* = 0.47), muscular endurance (+45%, *p* = 0.01), speed (-6%, *p* = 0.00) and aerobic capacity (+3, *p* = 0.42). These results reinforce the use of a periodised strength and conditioning programme to improve strength, power, muscular endurance, and aerobic capacity. Interestingly, this did not however translate into an improvement in upper arm angular velocity.

A non-significant increase (*p* = 0.47) in lower-body power was shown post-training intervention. Pre (38.7 ± 3.56 cm) and post (39.31 ± 2.88 cm) mean test scores for lower body power counter-movement jump (CMJ) showed a 2% increase, with only a trivial effect size (ES) (0.32) present (Table 2). The ES in the present study was similar to previous findings (ES = 0.42) by Carr and colleagues (28) who investigated changes in cricketers' strength, power and speed throughout a competitive season. Mean test scores were also similar to the minimum standards produced in the International Cricket Council High-Performance Programme (ICCHPP) testing battery (40 cm) and that of international level SBs (39.54 ± 3.35 cm) (15). Bowling velocity has been strongly correlated (r = 0.74), with lower body power (16). An increase in upper arm peak angular velocity can increase bowling arm speed and has the potential to translate into increases in bowling speed. Additionally, by decreasing knee flexion during front foot contact and generating high velocity momentum prior to ball release. Thus, higher levels of lower-body power should translate into increased bowling velocity. However, this was not seen in the current study which showed a non-significant increase (p = 0.77) in upper arm angular velocity post 14-week intervention.

Furthermore, a significant improvement in post 20m sprint time was seen (p = 0.00), mean pre (3.12 ± 0.05 sec) and post (2.93 ± 0.08 sec) values showed a 6% decrease in sprint time. Large ES (-4.71) were present (Table 2), with post-times being faster than the minimum ICCHPP standards (3.03 sec). The ES seen in this study was larger than those found in a similar study (ES = 1.68) in elite cricketers during a 20-week off-season period (10). Additionally, mean scores were faster to that of international level SBs (3.14 ± 0.13) (15) and comparable to that of elite English cricketers end of season 20m sprint times (3.05 ± 0.11 sec) (28). A possible explanation for the differences in results may be due to the specific and non-specific sprint training methods used across the numerous studies. For example, the current study prescribed two resistance gym-based sessions and one maximal aerobic session (MAS) per week that was progressively overloaded for the 14-week period whereas participants in the study by Weldon and colleagues (15) were prescribed three gym-based strength and conditioning sessions and one 90-minute prehabilitation session per week. Furthermore, the initial block of the periodised programme within the current study targeted longer stretch-shortening cycle exercises via slow plyometric landing drills and concentric hip extension movements (squat and deadlift variations) which has been shown (10) to assist in the acceleration phase of sprinting and may have increased velocity in the acceleration phase of the MAS session. Furthermore, as the resistance gym-based sessions progressed there was an emphasis on quick stretch-shortening cycle exercises via plyometric unilateral and bilateral exercises that target quicker ground contact times that may have transferred into quicker ground contact times during the maximal velocity stage of the MAS session. Significant evidence has shown that specific and non-specific sprint training methods can be used to develop speed characteristics by influencing changes in neural motor development, muscle cross-sectional area, biomechanical and coordination factors (10,29).

A non-significant increase in Yo-Yo IR Level 1 post-training was seen (p = 0.42) with mean pre (level 18.18 ± 1.92) and post (level 18.65 ± 2.44) values showing a 3% increase in completed levels with only a trivial ES (0.36) (Table 2). The reported ES was similar to those of high-performance seam bowlers SBs previously studied by Weldon and colleagues (15) (ES = 0.46) but lower than those reported in a study by Herridge and colleagues (10) (ES = 0.92). In the current study the mean increase was slightly below the ICCHPP minimum standards (level 18.70). On the other hand, the mean was almost identical to previous research in elite English cricketers (level 18.59 ± 1.40) (10) and slightly higher than those (level 18.17 ± 0.88) in the recent study by Weldon and colleagues (15). With seam bowlers having been shown to cover the greatest distances and achieve the highest intensities within the cricket team (30), it could be proposed that seam bowlers who possess higher aerobic endurance may be better placed to cope with the match demands. This has been recently reported by Webster and colleagues (18), who showed a positive relationship between tests of physical qualities and physical match demands in 50-over cricket. Importantly, the current programme has managed to influence cardiovascular fitness positively.

Lower body strength (hex bar deadlift) showed a significant increase post-training (p = 0.01) with mean pre (116.5 ± 17.86 kg) and post (148.66 ± 29.02 kg) values showing a 28% increase and a large ES (1.86) present (Table 2). Previous studies (33,37,16,34) have demonstrated a relationship between a more extended knee (>150°) during ball release and increased delivery speeds, while King and colleagues (38) associated ball speed with increased knee extension angle at ball release (r = 0.492, p = 0.027). This suggests increased knee extension creates a more effective lever which could allow for a more efficient transfer of momentum from the run-up through to ball release. However, this characteristic may also be associated with a greater chance of injury occurrence due to increased impact force (5-9 times body mass) is being absorbed by lower-back muscles (37). An effective strategy to negate these concerns is lower-body strength and increased levels of eccentric strength, which could assist in maintaining an extended knee and withstanding ground reaction forces during front foot contact during bowling (35).

A significant increase in upper body strength (bench press) (p = 0.001) was seen post-training with mean pre (61.66 ±14.02 kg) and post (75.83 ± 13.19 kg) values showing a 23% increase with a large ES (3.76) present (Table 2) and were higher than international SB's for 6RM bench press. Additionally, a significant increase in bent over row (p = 0.010) was seen post-training with mean pre (63.33 ± 12.11 kg) and post (148.66 ± 29.02 kg) showing a 28% increase with a large ES (1.63) present (Table 2). Furthermore, a significant increase in horizontal pull up (p = 0.01) was seen post-training with mean pre (15.5 ± 2.07) and post (22.5 ± 2.73) results showing a 45% increase with a large effect size (1.96) present (Table 2). This significant increase in upper body strength maybe due to the periodised programme including upper body exercises that progressively overloaded anterior and posterior muscle groups. Additionally, previous evidence suggests the most effective programmes in youth populations last over eight weeks and involve multiple sets (36). The current studies 14-week periodised programme, which was progressively overloaded seems to be consistent with the findings by Berhringer and colleagues (36). Previously, positive correlations between ball release speed and maximum upper body strength (r = 0.74) have been shown in junior and senior populations (16). During bowling the SB must overcome their own body mass and impart maximal velocity on to the cricket ball. This requires a proximal to distal movement pattern of the upper body like that exhibited in baseball pitching and javelin and involves humerus of the bowling arm circumducting, using the pectoralis major, deltoid and the latissimus dorsi muscles (21). Therefore, it could be suggested that SBs with increased levels of relative strength may be able to efficiently transfer force through the bowling arm prior to ball release, thus potentially increasing ball release speed, however, this was not seen in the results of the current study. Several reasons may explain the lack of increase in upper arm angular velocity. Previous studies (31,7) have identified the transfer of training effect principle which evaluates the required time or 'lag time' that is needed for motor learning strategies to show improvement in strength into performance. The 1-week period between the completion of the training model intervention and the post-testing may not have been enough time for increases in relative strength to enhance upper arm angular velocity. Furthermore, due to the complex nature of fast bowling a longer period may be needed to allow players to use any enhanced physical qualities within their bowling action, with a combined skills coaching and physical preparation approach potentially being more optimal in assisting the developing seam bowler increase their BRS.

LIMITATIONS

The sample size of developing seam bowlers was small; however, this was not only unavoidable due to the number of developing seam bowlers that were available, this sample constituted approximately 30% of the total cohort who fitted this inclusion criteria. In addition, the inclusion of a control group may have provided additional insight into the effectiveness of the training model, however, academy level athletes are required to undertake some form of strength and conditioning throughout the year so a non-training group would not be possible. Finally, other methods of measuring BRS, such as speed radar gun, could be used rather than the method used within this study (XSens), which may potentially detect any changes in BRS. Future research should consider the benefits of mixed-methods research approach, where biomechanical, technical & physical provision are closely aligned within developmental programmes.

CONCLUSIONS

The present study aimed to investigate the effects of a 14-week physical preparation programme on developing seam bowlers. Modern day cricket demands a high level of athleticism, as most game-changing situations require a combination of physical attributes such as strength, power, muscular endurance, aerobic capacity, and speed. Therefore, it is crucial that SBs are in peak physical condition at the start of the season and are able to maintain their fitness throughout the year. Importantly, this study found that through physical preparation developing SBs can be nearly as physically capable as adults. Interestingly, although physical improvements did not translate to increases in upper arm angular velocity, these findings not only link to making adolescent SBs more robust and resistant to injury but also assists coaches' duty of care within this population. Testing and developing physical qualities (strength, power, muscular endurance, speed, and aerobic capacity) to enhance performance in adolescent SBs should be the primary aim of strength and conditioning coaches (18,20). This will allow adolescent SBs to develop the requisite physical qualities that in theory should enhance playing performance and reduce the risk of injuries during their developing years.

CONFLICTS OF INTEREST AND SOURCE OF FUNDING

No funding was received from any funding agencies in the public, commercial or non-profit sectors.

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APPENDIX

APPENDIX A

Information Sheet for Potential Participants

My name is Scott Hislen, and I am a postgraduate student from the School of Life Sciences at Edinburgh Napier University. As part of my master's in research programme I am undertaking a research project over a 12-month period. The title of my research study is:

"The provision of a training model for the development of Fast Bowling performance"

The study will investigate the effectiveness of a training model to improve fast bowling performance in adolescent cricketers. You will undergo a battery of fitness tests (ball release speed, strength, power, aerobic endurance, and speed) will be used to provide baseline measures, monitor performance, and establish change post investigation. Following initial testing you will be required to attend gym and field-based exercises sessions. This will involve you following a resistance and aerobic based programme designed by the researcher who is an accredited Strength and Conditioning coach who will be in attendance for all sessions to provide guidance and support.
The findings from this study will be used to inform current coaching practice through the development of an age and stage appropriate training model in order to improve future fast bowling performance.
To take part in this study you must be part of Cricket Scotland performance youth programme and be identified as fast bowler or a developing fast bowler. You must be at least 15-21 years of age. You must be free from illness or injury (cardiovascular, neurological and or metabolic disease) and be free from pain or history of chronic pain and have no contraindications to exercise. Prior to the start of the study, you will be required to complete a physical activity and readiness questionnaire and the researcher may decline participation, should there be any queries regarding your ability to take part in the study.
If you agree to participate in the training model study, you will be required to attend Cricket Scotland Performance Academy at Edinburgh Napier University or at Cricket Scotland Headquarters at Mary Erskine Indoor Centre twice per week over the course of a 12-month period. The researcher will complete a risk assessment prior to commencement of the study to minimize any potential risks. You will be free to withdraw from the study at any stage without the need to provide a reason for doing so.
All data will be anonymized where possible and your name will be changed to a participant number. All data will be stored on a password secure electronic device and will only be made available to the researcher, supervisors and identified coaches. Any data gathered from this study will not have an influence on playing ability. This will be kept till the end of the study then will be destroyed in accordance with Edinburgh Napier University's data storage regulations.

If you require any further information and or have any questions, please feel free to contact me (S.Hislen@napier.ac.uk). Any questions relating to the project I cannot answer will be referred to my supervisor Director of Studies Dr Cedric English (c.english@napier.ac.uk)

If you have read and understood this information sheet, any questions you had have been answered, and you would like to be a participant in the study, please now see the consent form.

APPENDIX B

Edinburgh Napier University Research Consent Form

Practical Training Model Intervention

Edinburgh Napier University requires that all persons who participate in a research investigation provide their written consent to do so. Please read the following information below and sign it if you agree with what it says.

1. I freely and voluntarily consent to take part in this training model study.
2. I understand that the purpose of this study is to establish the effectiveness of the training model on performance and will take place over a period of 12 months at the Cricket Scotland Academy which is based in Edinburgh Napier University and Mary Erskine School.
3. I understand that my name will not be used for any other purposes and the researcher, project supervisors, and the Cricket Scotland youth performance coaching staff module will be the only parties to view the data gathered from the training model study. Additionally, I understand that my data will be shared with Cricket Scotland coaches but will not have an impact on my playing ability.
4. I also understand that if at any time during the 12-month training programme and or during the practical sessions I feel unable or unwilling to continue, I am free to be removed without prejudice and all data collected will be destroyed.
5. I understand my participation in this study is completely voluntary, and I may withdraw from it without negative consequences.
6. I have been given the opportunity to ask questions regarding the training model intervention including the requirements for the practical components over the 12-month period and my questions have been answered to my satisfaction.
7. I understand that all the data pertaining to the training model study will be stored on an encrypted mobile storage device and once completed all data pertaining to the study will be destroyed.
8. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

Participant's Signature Date

I have explained and defined in detail the nature of the training model study including practical activity and testing. Furthermore, I will retain one copy of the informed consent form for my records.

Researcher's Signature Date

APPENDIX C

	Block 1 = 2 gym based sessions per week for 4 weeks		
Movement Preparation	10 squats, 10 press ups, 10 walking lunges, 10 thoracic rotations, 10 hip openers, 10 box jumps (30cm, bilateral), 10 drop jumps (30cm, bilateral)		
Exercise	**Set 1**	**Set 2**	**Set 3**
Barbell Back Squat	3 x 10	3 x 10	3 x 10
Barbell Row	3 x 10	3 x 10	3 x 10
Romainian Deadlift	3 x 10	3 x 10	3 x 10
Trap Bar Deadlift	3 x 10	3 x 10	3 x 10
Military Press	3 x 10	3 x 10	3 x 10
Inverted Row (straight legs)	3 x 10	3 x 10	3 x 10
Front Plank	3 x 60sec	3 x 60sec	3 x 60sec
Side Plank	3 x 60sec	3 x 60sec	3 x 60sec
Isometric Side Hold Plate Press	3 x 10	3 x 10	3 x 10

	Block 2 = 2 gym based sessions per week for 4 weeks		
Movement Preparation	10 squats, 10 press ups, 10 walking lunges, 10 thoracic rotations, 10 hip openers, 10 box jumps (40cm, bilateral), 10 drop jumps (40cm, bilateral)		
Exercise	**Set 1**	**Set 2**	**Set 3**
Barbell Back Sqaut	3 x 8	3 x 8	3 x 8
Barbell Bench Press	3 x 8	3 x 8	3 x 8
Barbell Split Squat	3 x 8	3 x 8	3 x 8
Dumbbell Shoulder Press	3 x 8	3 x 8	3 x 8
Single Arm Row	3 x 8	3 x 8	3 x 8
Chin Up	3 x 6	3 x 6	3 x 6
Wide Stance Cable Rotation	3 x 12	3 x 12	3 x 12
Hamstring Slider	3 x 10	3 x 10	3 x 10
Kneeling Cable Rotation	3 x 12	3 x 12	3 x 12

	Block 3 = 2 gym based sessions per week for 4 weeks		
Movement Preparation	10 squats, 10 press ups, 10 walking lunges, 10 thoracic rotations, 10 hip openers, 10 box jumps (40cm, bilateral), 10 drops jumps (40cm, bilateral)		
Exercise	**Set 1**	**Set 2**	**Set 3**
Barbell Back Squat	3 x 6	3 x 6	3 x 6
Single Leg Romanian Deadlift (smith machine)	3 x 6	3 x 6	3 x 6
Trap Bar Deadlift	3 x 6	3 x 6	3 x 6
Barbell Shoulder Press	3 x 6	3 x 6	3 x 6
Single Arm Row	3 x 6	3 x 6	3 x 6
Med Ball Rotational Slam	3 x 10	3 x 10	3 x 10
Wide Stance Cable Rotation	3 x 10	3 x 10	3 x 10

	Block 4 = 2 gym based sessions per week for 2 weeks		
Movement Preparation	10 squats, 10 press ups, 10 walking lunges, 10 thoracic rotations, 10 hip openers, 10 box jumps (40cm, bilateral), 10 drop jumps (40cm, bilateral)		
Exercise	**Set 1**	**Set 2**	**Set 3**
Single Leg Romanian Deadlift (smith machine)	4 x 4	4 x 4	4 x 4
Trap Bar Deadlift	3 x 5	3 x 5	3 x 5
Barbell Bent Over Row	4 x 4	4 x 4	4 x 4
Barbeel Bench Press	4 x 4	4 x 4	4 x 4
Dumbbell Step Up	4 x 4	4 x 4	4 x 4
Trunk Circuit (10 minutes)	N/A	N/A	N/A

APPENDIX C (Continued)

Block 1	Distance
Participant 2	10 x 10 sec (48.84m) w/ 3 min rest x 2 = Total Distance (977m)
Participant 6	10 x 10 sec (53.46m) w/ 3 min rest x 2 = Total Distance (1,069m)
Participant 5	10 x 10 sec (53.46m) w/ 3 min rest x 2 = Total Distance (1,069m)
Participant 3	10 x 10 sec (51.92m) w/3 min rest x 2 = Total Distance (1038m)
Participant 4	10 x 10 sec (48.84m) w/ 3 min rest x 2 = Total Distance (977m)
Participant 1	10 x 10 sec (45.87m) w/3 min rest x 2 = Total Distance (917m)

Block 2	Distance
Participant 2	10 x 10 sec (48.84m) w/ 3 min rest x 3 = Total Distance (1,465m)
Participant 6	10 x 10 sec (53.46m) w/ 3 min rest x 3 = Total Distance (1,604m)
Participant 5	10 x 10 sec (53.46m) w/ 3 min rest x 3 = Total Distance (1,604m)
Participant 3	10 x 10 sec (51.92m) w/3 min rest x 3 = Total Distance (1,558m)
Participant 4	8 x 15 sec (79.2m) w/ 3 min rest x 2 = Total Distance (1,548m)
Participant 1	10 x 10 sec (75.06m) w/3 min rest x 2 = Total Distance (1,501m)

Block 3	Distance
Participant 2	10 x 15 sec (87.48m) w/ 3 min rest x 2 = Total Distance (1,749m)
Participant 6	10 x 15 sec (87.48m) w/ 3 min rest x 2 = Total Distance (1,749m)
Participant 5	10 x 15 sec (87.48m) w/ 3 min rest x 2 = Total Distance (1,749m)
Participant 3	8 x 15 sec (87.12m) w/ 3 min rest x 2 = Total Distance (1,699m)
Participant 4	10 x 10 sec (48.84m) w/ 3 min rest x 3 = Total Distance (1,954m)
Participant 1	10 x 10 sec (45.87m) w/3 min rest x 3 = Total Distance (1,835m)

Block 4	Distance
Participant 2	8 x 15 sec (79.2) w/ 3 min rest x 3 = Total Distance (1,900m)
Participant 6	10 x 15 sec (87.48) w/ 3 min rest x 3 = Total Distance (2,624m)
Participant 5	10 x 15 sec (87.48) w/ 3 min rest x 3 = Total Distance (2,624m)
Participant 3	8 x 15 sec (87.12) w/ 3 min rest x 3 = Total Distance (2,090m)
Participant 4	10 x 10 sec (48.84m) w/ 3 min rest x 3 = Total Distance (1,954m)
Participant 1	8 x 15 sec (79.2) w/ 3 min rest x 3 = Total Distance (1,900m)

APPENDIX D

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7	
	15.11.21	18.11.21	22.11.21	25.11.21	29.11.21	2.12.21	6.12.21	9.12.21	13.12.21	16.12.21	20.12.21	23.12.21	10.1.22	13.1.22
Participant														
1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓	x	x	✓	✓	x	✓
4	✓	✓	✓	✓	✓	✓	✓	✓	x	x	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓
6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	Week 8		Week 9		Week 10		Week 11		Week 12		Week 13		Week 14	
	17.1.22	20.1.22	24.1.22	27.1.22	31.1.22	3.2.22	7.2.22	10.2.22	14.2.22	17.2.22	21.2.22	24.2.22	28.2.22	3.3.22
Participant														
1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2		x	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3		✓	✓	✓	x	x	x	x	✓	✓	x	x	✓	✓
4		✓	✓	✓	x	x	x	x	✓	✓	x	x	✓	✓
5		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6		✓	✓	✓	x	x	✓	✓	✓	✓	✓	✓	✓	✓