Exploring adolescent fast bowling: a mixed methods approach

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Contents

Abstract

Introduction: Limited mixed methods research has been conducted into the physical and skills requirements of a developing fast bowler.

Methods: This mixed methods study explored the interrelationship between the physical and skill requirements in developing fast bowlers in two parts. Part one, involved scripted online interviews with six professional fast bowling cricket coaches and were analysed using reflexive thematic analysis. Part two involved implementing a training model for developing fast bowlers. Six developing academy-level fast bowlers (FB) (18.1 ± 1.1 years) completed a periodised bowling-specific programme. Pre/post-tests across various physical qualities were recorded with changes measured using a paired sample t-test ($p \leq 0.01$) and effect sizes.

Results: Interview themes indicate skill specific warm-ups can be used in skill sessions to physically and technically prepare fast bowlers, while strength and power abilities were perceived important characteristics of fast bowling performance. Fast bowling coaches and strength and conditioning coaches should consider these physical characteristics when designing programmes for developing fast bowlers. Additionally, coaches suggested individualised programmes with strength and conditioning coaches requiring a technical understanding of fast bowling. Post 14-week intervention, group relative changes showed improvement in strength (+8%), power (+2%), muscular endurance (+45%), speed (-6%) and aerobic capacity (+3).

Conclusion: A multi-disciplinary collaborative approach should be used to provide developing fast bowlers with individualised technical and physical support to optimise performance. Although positive improvements were recorded post intervention, further

work is needed on how this can increase bowling speed. Future research should consider the benefits of mixed methods research, where the technical and physical characteristics are closely aligned within developmental programmes, to enhance performance and reduce injury in this population.

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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, batter, seam bowler (fast/medium), spin bowler, wicket keeper and fielder, with players often fulfilling several of these roles. Within these roles, fast bowling has emerged the most physically demanding when compared to the other roles within the team (Petersen et al., 2009; Petersen et al., 2010; Stronach et al., 2014a; Stronach et al., 2014b; Weldon et al., 2021). This is due to the total distance covered during games, number and intensity of sprints and the repeated high ground reaction forces experienced during their delivery stride and front foot contact as they complete their bowling action (Bliss et al., 2020; Petersen et al., 2009; Weldon et al., 2021).

To monitor the physiological and physical demands the fast bowler experiences, Global Positioning System (GPS) has been used to provide skills and strength and conditioning coaches with numerical data on player movement patterns and distances covered during match and training scenarios, which informs individual training programme design and can monitor overall training load (Petersen et al., 2009; Petersen et al., 2010, 2011). In comparison to the other positions, fast bowlers (FB) covered 20-80% greater distance, completed 1.8-7 times greater distance during high-intensity movement patterns (sprinting and striding), sprinted more often (1.4-8 times as frequently), and had 35% less time to recover between high-intensity bouts. The distance a FB covers varies across formats and has been reported at 5.5 ± 0.4km for Twenty20 matches, 13.4 ± 0.7km for one-day matches, and 22.6 ± 2.1km during multi-day cricket (6 hours) (Petersen et al., 2010; Petersen et al., 2011). The differences in the physiological and physical demands experienced by FB's over the various game formats demonstrates the importance of conditioning practices matching the physical intensity required (Mukandi et al., 2014; Webster et al., 2020; Weldon, Clarke, et al., 2021).

Much of the published research in this area has focussed on adult cricketers which has led to a lack of data relating to the physiological and physical demands of fast bowling in youth populations. For example, adult cricket FB's have been shown to have similar injury rates to high-contact football codes, which has led injury prevention research for FB's (Moore et al., 2015). However, adolescent FB's are more susceptible to injury in their developing years (Arnold et al., 2017: Duggleby & Kumar, 1997). This is due to individuals having partially ossified lumbar vertebrae, immature articular discs which are more prone to micro-damage, elongated musculotendinous tissues and elastic intervertebral disks (Difiori et al., 2014). With Pote and Candice (2016) finding there was a distinct lack of strength and conditioning programmes for adolescent cricketers.

Additionally, adult based programmes may not consider the long-term development of youths/adolescents (Lloyd & Oliver, 2012). For example, younger athletes have been shown to develop and mature at differing speeds during childhood and adolescence. Lloyd and Oliver (2012) devised a youth physical development model (YPDM) that strength and conditioning coaches and physical education practitioners could implement with developing players from the early childhood (2 years of age) to adulthood (21+ years of age) which identify why and when the training component should be targeted e.g., fundamental movement skills. Each stage of the model is designed to develop athletes' physical capacities such as strength, power and aerobic endurance based on their chronological age, age periods, growth rate, maturational status and training adaptation. This provides practitioners with a clearer understanding of the chronological, physical and maturational differences within youth populations which they suggest should allow for the holistic development of youth and adolescent athletes. Furthermore, an effective strength and conditioning strategy should not only reduce soft-tissue injuries but also benefit player performance (Finamore, 1992).

In terms of skill execution, the FB's main aim during performance is to dismiss opposing batters, as well as limit the number of runs scored during the game. For the bowler to successfully deliver the ball to the batsman a series of correctly sequenced movements within four distinct phases has been seen to be required (Portus et al., 2004). These phases have been defined as the run-up, pre-delivery stride, delivery stride and follow-through (Portus et al., 2004), with Felton et al. (2020) suggesting it is advantageous if a bowler can perform these phases in quick succession to reduce the batman's decision-making ability. Limiting the batman's opportunity to choose the correct shot to play in order to score runs, increases the chance of the bowler successfully dismissing the batter. One strategy that FB's 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 (Callaghan et al., 2021a; Callaghan et al., 2021b). 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 (Johnstone et al., 2014; Mukandi et al., 2014: Callaghan et al., 2020). During the delivery stride the bowler experiences high vertical and breaking ground reaction forces (GRF) at back and front foot contact (FFC) in both horizontal and vertical planes as they jump into the bowling crease (Callaghan et al., 2021). Upon landing the fast bowler endures GRFs of up to 9.5x their bodyweight (Noakes & Durandt, 2000). As they release the ball and follow through the delivery sequence is complete. Normally, this sequence is repeated six times and is known as an over, with the number of overs delivered varying depending on the match format and situation. As a result, the number of overs delivered will increase the physical and physiological demands the FB will experience. For instance, Petersen et al., (2010) showed that T20 was 22% and 43% more intensive for elite FB than that experienced during one-day and multi-day respectively. Therefore, appropriate physical preparation that ensures FB's can cope with the physical and physiological demands should be provided throughout the season.

There are four main FB action types, namely, front-on, semi-open, side-on and mixed action (Portus et al., 2004). Front-on describes an action with a shoulder segment angle of <250° at back foot contact, a hip-shoulder separation angle of <30° at back foot contact and a shoulder counter-rotation of <30° (Portus et al., 2004). Additionally, semi-open describes an action with a shoulder segment angle range of 210-240° at backfoot contact with a hip-shoulder separation angle of <30° at back foot contact and a shoulder counter-rotation of <30°. Furthermore, side-on describes an action with a shoulder segment angle of >240° at back foot contact with a hip-shoulder separation angle of <30° at back foot contact and a shoulder counter rotation angle of <30° (Portus et al., 2004).

The mixed action is associated with increased rates of low back injuries (LBI) (Burnett et al., 1995; Elliott, 2000; Foster et al., 1989; Portus et al., 2004; Ranson et al., 2009). Biomechanical analysis suggests that a mixed action is characterised by a large degree of shoulder counter rotation or hip-shoulder separation angle (30°≥) in the longitudinal and transverse axes. This occurs between back foot contact (BFC) and front foot contact (FFC) during delivery stride places a higher degree of stress on the lumbar spine relative to the other action's requirements. This has been shown to increase lumbar spine injury risk in adult populations (Burnett et al., 1995; Elliott, 2000; Foster et al., 1989; Portus et al., 2004; Ranson et al., 2009). In contrast, Bayne et al. (2015) found no observable differences in the amount of shoulder counter-rotation utilised by FB's who did and did not sustain an injury ($p > 0.05$). The failure to link these previously established risk factors could be due to the multifactorial nature of low-back injuries such as low back flexibility, trunk asymmetry and trunk muscle function and bowling load (Johnson et al., 2012). Lumbar spine injuries are well documented within FB's, with low back injuries being the most common, and lumbar stress fractures the most serious leading to loss of training and match time (Alway et al., 2019; Bayne et al., 2016; Forrest et al., 2017). This is of particular interest within adolescent populations who are vulnerable to certain injuries during their developing years (Arnold et al., 2017; Duggleby & Kumar, 1997). For example, within adolescent individuals the lumbar vertebrae are not yet fully ossified (Forrest et al., 2014). This makes the elastic intervertebral discs and immature articular cartilage susceptible to micro-damage and elongated musculotendinous tissues (Davies et al., 2008), leading to non-contact injuries that typically effect the shoulder, lower back, and lower limbs. This evidence resulted in researchers providing coaches with exercise-based injury prevention strategies to assist in the reduction of injuries in adolescent FB's (Forrest et al., 2018).

A further area of research interest has been the physiological profile of the fast bowler (Johnstone, et al., 2014; Johnstone & Ford, 2010; Webster et al., 2020; Weldon et al., 2021). Elite FB's and coaches believe there are several characteristics required to be a successful fast bowler, namely, coordination, strength, speed, endurance, a tall stature, and an ability to withstand internal and external loads (Phillips et al., 2014). These physical qualities have been investigated with several studies showing FB's who are taller and possess greater anterior-posterior chest depth, leaner upper body and large arm girths have higher ball release speeds (Glazier et al., 2000; Johnstone, et al., 2014; Pyne et al., 2006; Stuelcken et al., 2007). Even though, strength and conditioning guidelines for FB's have become more prevalent (Mukandi et al., 2014; Stronach et al., 2014); there is still, limited research within youth populations (14-18 years in males). These limitations provide a significant opportunity to explore the developing fast bowler due to the variance in developmental rate in youth populations (Lloyd & Oliver, 2012; McQuilliam et al., 2020). Therefore, research within this area could assist strength and conditioning coaches provide safe and effective physical preparation programmes in youth cricketers with the view to optimising performance and reducing injury risk.

Finally, there has been limited research conducted on the coach's perspective of the technical, physical, and psychological requirements needed by an adolescent/developing fast bowler. Phillips et al. (2010a and 2014b) have provided some research into the development of fast bowling experts in cricket and the acquisition of expertise in cricket fast bowling. Their original paper in 2010 (Phillips et al., 2010a) found unique interacting constraints resulted in non-linear trajectories of fast bowling expertise and identified unstructured practice activities, optimising learning processes and strong support roles from senior players as playing a key role in fast bowling development. Within their investigation Phillips and colleagues (Phillips et al., 2014b) found that a lack of formal coaching at an early age enabled them to develop their skills through discovery learning rather than over prescriptive coaching. Additionally, they identify various technical and physical attributes such as lever length, strength, flexibility, coordination, and ball release height that are beneficial for fast bowling but acknowledge that individual differences within FB's do exist (Philips et al., 2014b). These results suggest there is some ambiguity regarding what coaches perceive to be the technical, physical, and psychological characteristics needed to be a successful developing fast bowler. Therefore, further research into the process of identifying a developing fast bowler and the coaches' perspectives on the process of the technical and physical characteristics needed could assist other skills coaches and strength and conditioning coaches to support developing FB's more effectively over the long term.

Aims of the research interventions

Study 1:

To identify the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowler.

Research Question

Due to the subjective nature of fast bowling, is it possible to gain consensus across, physical, psychological, and technical variable and the support mechanisms required to develop an appropriate framework.

The aim of this research investigation is to determine the key technical, physical and psychological requirements needed by an adolescent/developing fast bowler?

Study 2:

The aim of this research investigation is to develop and test an appropriate training model for fast bowling performance in cricket.

Research Question

Can age-appropriate training model improve fast bowling performance in adolescent cricketers.

Hypothesis

A physical preparation programme will improve physical performance and bowling arm rotational speed in developing fast bowlers.

Literature Review

Introduction

This literature review will attempt to cover the areas which will not only directly address the research aims, but also cover areas which have an indirect impact on the development of adolescent fast bowlers from a skills and physical preparation perspective. With an ever-increasing understanding of the physical, psychological, and technical demands of fast bowling the need to physically prepare FB's for the various formats of cricket to optimise performance and reduce the risk of potential injuries is vitally important (Johnstone & Ford, 2010; Johnstone et al., 2014; Kiely, 2020; Kiely et al., 2021; Mukandi et al., 2014; Stronach et al., 2014a; Stronach et al., 2014b). A key aspect of optimising performance and reducing the risk of potential injuries is the design of evidence-based physical preparation programmes that can be used within adult and adolescent fast bowling populations. Due to the variance in fast bowling technique and individual variation, especially during adolescence, this review will focus on the key technical and physiological characteristics required for successful performance in FB from a coaching and strength and conditioning training model design perspective. It is hoped this review will provide skills and strength and conditioning coaches with information that can be used to assist in physical preparation and optimise performance.

Biomechanics of Fast bowling

Several factors relating to increasing BRS in junior and senior FB's have been investigated in the research previously (e.g., trunk kinematics, run-up, bowling shoulder kinematics and front leg kinematics) (Glazier er al., 2000; Loram et al., 2005; Portus et al., 2007; Worthington et al., 2013a). Bowlers exhibiting larger amounts of trunk flexion up to the point of ball release to delay the onset of bowling arm circumduction have been shown to achieve higher BRS (Worthington et al., 2013b). An increased shoulder angle during front-foot contact, as a consequence of trunk flexion, provides a larger range of motion for the shoulder to move through whilst generating BRS. This allows greater torques to be exerted at the glenohumeral joint

(Salter et al., 2007; Worthington et al., 2013b). This suggests, the further back the arm is positioned relative to the trunk at ball release, the higher the potential there is to increase BRS.

Run-up speed has been shown to have a strong (r = 0.58) to very strong relationship (r = 0. 78) with BRS (Feros et al., 2012). For example, Duffield et al. (2009) demonstrated a strong (r = 0.52) to very strong positive (r = 0.700) relationship between the faster the bowler's horizontal velocity was during the final 5 meters of their run-up and BRS, suggesting increasing horizontal velocity during the final 5 meters of the bowler's run-up can increase BRS. However, the small sample size (n = 6), does mean these results should be viewed with a note of caution. Previously, Glazier et al. (2000), found comparable results and concluded bowling actions that permitted increased horizontal velocity in the final strides of the run-up produced higher BRS. Higher linear velocity in the run-up may be warranted if: (a) it does not increase the bowlers risk of injury due to the higher GRF's impacting on the body, (b) the bowlers bowling mechanics are not altered due to any changes in stride length or stride frequency, and (c) the momentum gained from the increased velocity during the run-up can be transferred from the body to the ball (Elliot et al., 1986; Portus et al., 2000; Salter et al., 2008). As a result of these provisions, strength and conditioning coaches should consider developing and optimising linear running mechanics to assist in improving a bowler's performance and BRS.

Another noted area of interest is the relationship between a more extended front knee angle at front foot contact (> 150°) and higher BRS (Loram et al., 2005; Pyne et al., 2002; Wormgoor et al., 2008). The extension of the front knee during front-foot contact facilitates the conversion of the linear momentum from the run-up into angular momentum around the front foot. This enables the swift deceleration of the pelvis

(Portus et al., 2007; Worthington et al., 2013b), which consequently propels the trunk forward about the pelvis. Additionally, the increased radial distance between the bowler's extended arm and the point of front-foot contact augments the tangential end point velocity (Worthington et al., 2013b). Although there is a clear advantage of the extended front knee at the point of front-foot contact, this trait may also be associated with an increased injury risk due to the increased impact force on the body (e.g., 5-9 times body mass), which is absorbed by the structures of the lower back (Portus et al., 2007).

Physiological profile and physical demands

In the past, researchers have investigated the impact of various anthropometric factors such as height, weight, lean mass, and limb length on fast bowling performance (Glazier et al., 2000; Johnstone et al., 2014; Johnstone & Ford, 2010; Pyne et al., 2006; Stronach et al., 2014). Evidence from previous studies have found that FB's of larger stature and strength generally have higher ball release velocity in comparison to their smaller counterparts (Pyne et al., 2006). However, it should be noted that all populations within the previous studies were classified as adult, so the usefulness of the result as it relates to adolescent populations should be viewed with caution due to adolescent populations having non-linear growth development during this time-period (Llyod et al., 2014). For example, an adolescent FB who may be considered small in stature and therefore not considered as having the potential to be a FB during the early talent identification, could develop into a larger stature in their developing years, which maybe has been shown to be a characteristic associated with successful fast bowling.

Within elite fast bowling population, FB's have a tall stature ranging from 1.83 and 1.92m (Duffield et al., 2009; Glazier et al., 2000; Pyne et al., 2006; Stuelcken et al., 2007), which is taller when compared to batter (1.76-1.85m) (Christie et al., 2008; Johnstone & Ford, 2010). Johnstone et al. (2014) highlighted that this is significantly higher than the wider male population (mean1.77-1.78m). This taller stature was previously seen to have a positive impact on ball release speed due the ball release angle, bounce from pitch and force production (Johnstone et al., 2014). This was highlighted by evidencing that 80% of the leading test match fast bowling wicket takers were over 1.83m. A higher ball release angle allows for extra bounce to be extracted from the pitch (Stuelcken et al., 2007), which can decrease the time the batsman has to decide on their shot, thus increasing the opportunity to take a wicket.

Although height is non-modifiable, it may be important in terms of talent identification and player selection with a taller stature being an important observable physical characteristic for a coach. It has also been suggested that bowling arm length is a predictor of bowling speed in FB's, with Glazier et al. (2000) reporting a high correlation between the length of bowling arm and ball release speed (r = 0.58). The findings of Glazier et al. (2000) should carry some credibility, given that the peak linear speed of the wrist is related to the length of the radius for any given angular velocity. Therefore, a greater arm length should produce a greater linear speed for the wrist and result in a higher ball release speed. Although logical in theory, a longer arm length will result in a greater moment of inertia of that segment, meaning a greater rotational resistance (Johnstone et al., 2014), which may require taller FB's to have greater levels of relative strength in comparison to their smaller counterparts. In contrast to the work of Pyne et al. (2006) and Stuelcken et al. (2007), Glazier et al. (2000) did not use professional FB's and the small sample size (n = 9), may cast some doubt on the on the practical application of their outcomes. This together with a small sample size (n = 9), may be a reason subsequent studies have contradicted these results (Pyne et al., 2006; Stuelcken et al., 2007).

A further area of interest is that of body mass, with some studies showing FB's mean body mass ranging from 72.2 -87.9kg (Glazier et al., 2000; Johnstone et al., 2014; Johnstone & Ford, 2010; Lees et al., 2016; Pyne et al., 2006; Stuelcken et al., 2007). To contextualise these figures, similar sports activities involving the throwing of projectile implements, such as baseball, have revealed body masses of 87.6 ± 4.6kg (Carvajal et al., 2009), and 90.8 ± 9.7kg in elite junior javelin throwers (Coh et al., 2001). Although there are some differences in technique and physiological demands, when comparing body mass, these results suggest FB's are relatively lighter in total body mass in comparison to other projectile throwing sports. A potential explanation for this is the movement demands associated with cricket. For example, FB's can cover up to 22.6 ± 2.1km, during a day's play (3 x 2h sessions) of multi-day cricket. (Petersen et al., 2010).. Therefore, leaner physiques are more suited to large running demands and for high performance activities, indicating strength and conditioning coaches should design physical preparation programmes that promote strong and lean physiques to suit the physical demands of the game.

Finally, FB's with larger physical stature and increased strength levels generally have a higher ball release velocity (Pyne et al., 2006). This was supported by previous findings by Portus et al. (2000) who found that male FB's with a larger and leaner upper torso bowled consistently faster than those with a smaller and less lean upper torso. Similarly, Stuelken et al. (2007) found that male FB's had larger anterior-posterior chest depths (21.2 ± 2.0cm) , calf girths (39.0 ± 2.2 cm) and arm girths (28.9 ± 2.1 cm) relative to height, which may assist in achieving higher ball speeds due to the muscle at a cross-sectional area being related to its contractile capability and consequently the power and speed it can produce (Cormie et al., 2011; Johnstone et al, 2014). Larger chest and arm girths may also be beneficial from an injury prevention perspective by providing increased stability to the glenohumeral joint during the bowling action. For example, during the bowling action, the rotator cuff muscles of the bowling arm must actively stabilise and support the shoulder joint by centring the humeral head in the glenoid cavity which can lead to glenohumeral joint distraction (Hackney., 1996; Wilk et al., 1997) FB's with larger and leaner arm girths maybe able to reduce this glenohumeral distraction which could lead to a reduced risk of injury and improve bowling performance. With the correlation between a FB's leaner anthropometry, larger upper body statures and ball speed, strength and conditioning coaches need to design well-balanced programmes that consider muscle size and overall body composition. This can be achieved by programming multi-joint upper and lower body exercises such as squats (unilateral & bilateral), deadlift variations (unilateral & bilateral), bench press variations (unilateral & bilateral) and shoulder press variations (unilateral & bilateral), upper body horizontal pull variations (unilateral & bilateral) (Johnstone et al., 2014; Johnstone & Ford, 2010; Kiely, 2020; Mukandi et al., 2014).

Physiological requirements

Considering the different formats of cricket, the physiological demands vary considerably in terms of physiological responses, total distance covered and number of sprints across the distinct roles within the team (Carr et al., 2015; Johnstone & Ford, 2010). Several studies have investigated variability in movement patterns and match demands (Sholto-Douglas et al., 2020; Webster et al., 2020; Weldon, Clarke, et al., 2021), with FB's performing the greatest amount of work of all the cricket skills across all formats of the game (Petersen et al., 2010). In a one-day innings FB's covered a total distance of 13.4 ± 0.7km (mean ± 90% CI) compared to batter who covered a total distance of 8.7 ± 0.6km (mean ± 90% CI) and wicketkeepers who covered a total distance of 9.5km. Additionally, total distanced covered by FB's during one-day international noted 69% spent walking 16% jogging, 9% running and 7% sprinting (Petersen et al., 2010). Furthermore, repeated sprint data (defined as a minimum of three sprints with a mean recovery duration of less than 60 seconds), showed only FB's undertook sprinting in clusters. These clusters occurred mainly during bowling spells but can also take place during fielding tasks in between bowling overs. Additionally, across all formats FB's had had at least 35% less recovery time when compared to the other positions. Furthermore, Petersen et al. (2010) demonstrated that Twenty20 cricket was 22% and 43% more intensive for FB's when compared to one-day and multi-day formats, in terms of hourly sprint distance completed. However, the total sprinting distance in Twenty20 and one-day was only 39% and 80% of the daily (6h) 1.4km sprinted during multi-day cricket. During Twenty20 games FB's covered 340m and 400m greater distance per hour than during one-day and multi-day cricket which suggests Twenty20 is more intensive than one-day and multi-day cricket in terms of hourly sprint distance. Therefore, Twenty20 and one-day cricket required only 24 and 59% of the total distance completed in the multi-day format (Petersen et al., 2010). In an earlier study Petersen et al., (2009) set out to quantify the movement patterns in Twenty20 cricket. Results showed that during an 80min fielding innings cricketers covered 6.4.-8.5km, with 0.1 – 0.7km of this distance spent at sprinting velocities. The reported sprinting distances accounted for 9%, 7%, 7%, 2% and 1% of the total distance covered for FB's, batting, fielding, spin bowling and wicketkeeping, respectively. In contrast, walking accounted for 66% of total distance covered by spin bowlers, wicketkeepers, and the batter, but only 50% of the total distance covered by fielders and FB’s (Petersen et al., 2009). Additionally, FB’s had 11 more sprints (ES=0.66), 33 more high intensity efforts (ES=0.60) than fielders. These results are consistent with previous studies by Petersen and colleagues (2010) who demonstrated that FB’s have the highest workloads in comparison to the other playing positions. When prescribing position specific training programmes, it would be optimal for coaches to consider the movement demands of that position to physically prepare the player for the match requirements.

Recently, Bliss et al. (2020) set out to compare the variability and physical demands of FB’s in one day games and Twenty20 international matches across five-years. Data showed Twenty20 matches place more physical demands on the FB’s than one day games relative to the minutes played, which is demonstrated in the number of accelerations and decelerations, meters covered per minute and distances covered in speed bands. These results show that the physical demands of one day games and Twenty20 are not interchangeable and specific physical preparation by strength and conditioning coaches for different formats may be required to provide individualised support for FB’s. More recently, in 2022 Bliss and colleagues (2022) aimed to investigate the physical demands of test match cricket during fielding in seam bowlers. Results showed male seam bowlers in test match cricket face high physical demands during fielding, with significant variability across matches. Specifically, the average distance covered by seam bowlers during fielding was 2.9 km per day, with a maximum distance of 5.8 km covered in a single day. The study also found that there was significant variability in physical demands across matches, with some matches requiring much higher levels of physical exertion than others. Furthermore, the study found that match location (home vs away) had a significant impact on the physical demands placed on seam bowlers, with away matches generally requiring more physical exertion than home matches. These findings highlight the importance of understanding the physical demands of test match cricket for developing effective training programs for seam bowlers to help them manage these demands and perform at their best.

In a 2011 study, Petersen and colleagues set out to quantify time-motion and physiological characteristics of various cricket training activities and compare them to known match demands. Global positioning system (GPS) data and heart rate (HR) was used to provide descriptive quantitative data on the physiological demands of training activities, with those of an actual cricket match. Forty-two players had their data from training sessions compared to published game data from the Cricket Australia Emerging Players Tournaments played in 2007 and 2008. The results showed FB's had comparable mean heart rates in simulation and skills drills but lower in conditioning drills. When considering intensity (total distance covered), similar levels were reached between Twenty20, skill drills and simulation, however, higher levels were achieved during conditioning drills. More recently, Vickery et al. (2016) compared the physical and technical demands of cricket players during training and match-play. To determine the comparative demands of training, two methods (net-based and fielding training, and centre-wicket game training) were compared with that of One-Day match demands. GPS, Rating of Perceived Exertion (RPE) and HR data were gathered to compare training and match demands. The results for the FB's showed a greater time (d = -1.0 [-5.6 to 3.6] spent above 75% (HRmax) during traditional net-based cricket training session compared with One-Day matches. However, this did not result in higher RPE values as both training formats reported lower training load values (training load = RPE x session minutes) post session. Fast bowlers did record greater relative distances at high intensity when compared to match play, 1,573$m \cdot h^{-1}$ and

977m·h^{-1}, respectively. Conversely, lower relative distance was covered during center-wicket training when compared to match play, 771m·h^{-1} and 997m·h^{-1}, respectively. The results from this study demonstrated that FB's were exposed to greater physical demands during traditional net-based cricket training compared to One-Day matches, in contrast to centre-wicket training which produced lower physical and physiological demands. The comparatively lower physical and physiological demands during centre-wicket simulations could be due to the greater size of the training environment. These results differ with previous research (Vickery et al., 2014) which suggests that a game-based approach is more effective at replicating match intensity. The differences between the two studies may be explained by the differences in sizes of environment. In their previous study (Vickery et al., 2014a), all players were restricted to an enclosed area, whereas the current study (Vickery et al., 2016b) trained on a full-size cricket field. The full-size cricket field may have resulted in an increased number of low-intensity movements such as walking and or jogging. These findings suggest that in some cases the physical and physiological demands experienced in training-based conditions do not reflect the match demands across the different formats. Further research in this area would assist skills and strength and conditioning coaches to prepare fast bowlers for the match demand more effectively. Webster et al. (2018) compared the physical demands of a One-Day Game (ODG) and the training sessions of provincial cricket players using GPS. They reported high-intensity movement patterns for provincial FB's for both ODG and training did not differ, which shows physical effort in terms of movement patterns for provisional FB's is closely matched in high-intensity and low-intensity movement categories. Fast bowlers also covered the greatest absolute distances (8,790m) in most movement categories e.g., walking (6,234m), jogging (1347m), striding (291m) and sprinting (567m) when compared to the other sub-disciplines. The sprinting demands during training, in terms of high intensity movement patterns (mean = 674m) and maximum (193 b·min^{-1}) and average heart rates (170 b·min^{-1}) closely matched the demands of an ODG in terms of high intensity movement patterns (mean = 567m), maximum and average heart rate with traditional net-based training simulating the high-intensity movement patterns for FB's. However, from the data presented in Webster and colleagues' paper (2018) it was not possible to extrapolate the data for maximum and average heart rate. This could be a potential reason as to why no differences were seen between the high-intensity movement patterns in training and ODG. These results agree with previous findings (Petersen et al., 2010) who also showed FB's consistently performed at greater distances than the other positions within the team (Johnstone et al, 2014; Johnstone & Ford, 2010; Weldon et al., 2021). Although, the validity and reliability of GPS devices has been questioned (Vickery et al., 2014c), such data can be used to assist strength and conditioning coaches in designing position specific physical preparation programmes for FB's that meet the physical demands of match competition. When designing conditioning workloads as part of the FB's physical preparation programming, strength and conditioning coaches could, where possible use GPS data gathered from time motion analysis to develop their knowledge of positional differences when design conditioning programmes that replicate the physical demands of fast bowling in the different formats. Additionally, the use of GPS data may allow strength and conditioning coaches to monitor and identify potential spikes in workload which has been shown to increase the risk of injury in some instances (McNamara et al., 2017).

As fast bowling requires repeated sprinting, repeated high-intensity efforts and high levels of strength, physical preparation programmes should match the demands of fast bowling (Mukandi et al., 2014). With this in mind, strength and conditioning has been used to physically prepare players, enhance performance, and reduce injury risk through gym and field-based exercise programming (Bliss et al., 2021; Kiely, 2020; Mukandi et al., 2014; Webster et al., 2020; Weldon, Clarke, et al., 2021). In a review by Johnstone et al. (2014) the researchers identified an incomplete evidence base that strength and conditioning coaches could access which led to conditioning programmes being designed based on hypothetical or anecdotal data. Evidence-based data along with industry-based qualifications would assist strength and conditioning coaches provide more individualised physical preparation support to FB’s. In their review Johnstone et al. (2014) identified several areas for consideration when physically preparing FB’s including the need for FB’s 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 gleno-humeral joint (Stuelcken et al., 2007). 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 mechanism associated with fast bowling (Johnstone et al., 2014). 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 fast bowler from a technical standpoint (maintenance of an extended front knee) and physically (withstanding fatigue) (Johnstone et al., 2014; Mukandi et al., 2014).

Understanding the physiological profile of the FB plays a vital role in physical preparation and workload monitoring. Another area of research interest has been to investigate the physiological profile and the physical preparation of a FB. Several studies (Johnstone et al., 2014; Webster et al., 2020; Weldon et al., 2021) aimed to create a more detailed physiological profile of FB's by establishing the relationship between physical match performance and tests of physical fitness qualities. Weldon et al. (2020), set out to develop a physiological profile of international cricketers and investigate the differences between batter and bowlers. Their results showed that batter had significantly higher lower-body counter-movement jump test scores (45.21cm vs 39.54cm) when compared to bowlers. The results were comparable to Indian state level and national level cricketers who in a different lower body power test (broad jump), showed greater scores when compared to bowlers (233.55cm vs 216.85cm) (Lamani & Tiwari, 2016). Although the broad jump involves a maximal horizontal jump and the CMJ involves a maximal vertical jump, both jumps require similar maximal triple extension of the ankles, knees, and hips to produce the jump action. The scores in the Weldon (2020) paper were in contrast to an earlier study where elite English FB's performed better than batter for the counter-movement jump (45.7cm vs 43.9cm) (Johnstone & Ford, 2010). A potential reason for the differences in the lower body power results may be due to anthropometrical differences between the batters and bowlers in the Weldon study who were 77.0kg and 73.64kg, respectively. The increased overall mass within the batting group could have had a positive impact on their ability to produce force in the vertical jump. Additionally, Weldon et al. (2020) demonstrated that the 8-week strength and power development programme completed by batters and bowlers produced similar scores for counter-movement jump lower-body power (batter = 45.21cm & bowler = 39.54cm), 6RM bench press strength (batter = 67.11kg & bowler = 67.19kg), 20m speed (batter = 3.14sec & bowler = 3.12sec) and Yo-Yo intermittent recovery , Level 1, aerobic fitness (batter = level 18.17 & bowler = level 18.56). However, individual and intra-positional differences existed between seam and spin bowlers. This supports the notion that physical tests and programming should be skill related to fully develop the players physical qualities. In a similar study, Webster et al., (2020) investigated the relationship between physical fitness and physical demands of 50-over cricket in FB’s. Fifteen professional FB’s underwent a series of anthropometric and physical tests and had Global Positioning System (GPS) data gathered from six 50-over matches to provide an overview of typical 50-over match demands. They found greater physical performance can be attributed to superior physical qualities. FB’s achieved high scores in the aerobic based test (Yo-Yo Intermittent Recovery Test Level 1) which contrasts with earlier results previously reported (Johnstone & Ford, 2010). However, in the Johnstone and Ford (2010) study the multi-stage fitness test was used for aerobic testing, whereas Webster et al. (2020) used the Yo-Yo Intermittent Recovery Test Level 1 which as with the multi-stage fitness requires participants to run between 20m but does not require continuous turning at each level but rather allows for a 10-second recovery at the designated area. This difference allows for rest periods and reduces the number of 180° turns required and therefore may be more reflective of the movement and physiological demands of fast bowling (Krustrup et al., 2021). Additionally, one notable trend highlighted by Webster et al. (2020) was the percentage of low-intensity work with 67% of total distance being at less than 7 km/hr, confirming that 70% of the total distance covered in a one-day game is at lower intensities (Petersen et al., 2010). With the high intensity nature of FB these periods of low intensity effort can assist in promoting recovery during bowling spells. Test results across all physical qualities and physical match demands suggest the importance of lower-limb power, speed, and intermittent activity abilities to enhance physical match performance. Understanding the physical demands and physiological requirements of fast bowling during training and match play, as it relates to the adolescent fast bowler, is vital when designing physical preparation programmes. This is due to physical and physiological differences that occur during adolescence (Forrest et al., 2018: Lloyd et al., 2014). For example, as younger athletes physically mature, they have the ability to become relatively more anaerobic. Various factors such as increase in muscle mass, rate of anaerobic glycolysis, and maximal oxygen debt per unit of body mass (Malina et al., 2004). These adaptations can increase their ability to produce metabolic power, but experience more fatigue. Which, as a consequence, will result in the younger athlete taking longer to recover.

Injuries

Due to the physical demands and high ground reaction forces endured, FB's have exhibited higher incidences of injuries when compared to the other positions within the cricket team (Stretch & Raffan, 2011). Injury prevention is an important area of consideration when establishing an appropriate training programme, as injuries lead to missed training, loss of playing time and acute/chronic pain (Forrest et al., 2018).

Within this area, previous research has focused on adolescent FB's who are susceptible to certain injuries during developmental growth, such as lower lumbar bone stress fractures, growth-related conditions in the lower extremities e.g., Osgood-Schlatter disease, and overuse injuries (Arnold et al., 2017; Duggleby & Kumar, 1997). Understanding the multifactorial nature of fast bowler injury incidence is vital to the strength and conditioning coach as providing an appropriate and evidence-based physical preparation programmes that will optimise performance and mitigate injury risk factors. Several studies (Alway et al., 2019; Bayne et al., 2016; Johnson et al., 2012: Ranson et al., 2009) have investigated the potential risk factors associated with injury incidence in FB's. These areas of interest have included bowling workload and investigations into the bowling action. More recent investigations have moved towards a lack of lumbo-pelvic control as being one of the more relevant factors (Forrest et al., 2018). With these risk factors being associated with an increase in incidence of overuse injuries, with the majority of these risk-factors being the cause of low back injuries (LBI) and lumbar stress fracture (LSF). Ranson et al. (2009) conducted a study to determine whether a two-year coaching intervention could improve bowling action kinematics; low back injury risk factors and increases in ball speed. They concluded that coaching interventions aimed at producing a more side-on alignment was shown to significantly reduce shoulder alignment at back-foot contact which reduced shoulder counter-rotation, which may reduce the stresses placed on the lower back and therefore reduce potential injury risk. During their initial testing thirteen of the fourteen FB who took part were classified as having a mixed action. When tested again after the two-year period, that number was reduced to nine, with four now having a shoulder counter rotation of under 30°. Similar results were observed in a previous study by Elliot and Khangure (2002), who also found that coaching interventions were successful in reducing shoulder counter-rotation in elite FB's during the bowler's delivery stride. This suggests that FB technique can be changed to reduce the stress placed on the lumbar spine previously associated by a mixed action but may not lead to higher BRS. Furthermore, coaches can implement specific coaching interventions to modify bowling action kinematics that may reduce the risk of injury in some FB's, which should allow players to be more available for skills and physical preparation training throughout the season. Additionally, strength and conditioning coaches can programme to increase FB's relative strength which theoretically should allow them to hold key positions throughout their bowling action e.g., a more side-on position, which could optimise performance and reduce the risk of potential injury. In a separate study, Bayne et al. (2016) set out to examine intrinsic risk factors, whole-body and detailed lumbo-pelvic biomechanics, and bowling load in a prospective cohort study, which examined low back injuries in adolescent fast FB's. They examined the relationship between pelvic-femoral control (using a single leg decline squat test) and bowling biomechanics to investigate a potential association between dynamic screening tools, fast bowling mechanics and injury risk. Forty-six male FB's from district/state level junior squads who were free from low back pain the preceding three months took part in initial testing with fifteen withdrawing due to acute or chronic lumbar bone stress abnormalities being identified during MRI screening. An additional six bowlers withdrew during the season. The remaining twenty-five participants were followed for injury surveillance over a 6-month period. On completion of the study thirteen FB's (52%) demonstrated no LBI with the remaining twelve players were considered injured based on acute and chronic lumbar bone stress abnormalities seen in magnetic resonance screening results. The results showed the injured group had greater trunk lateral flexion contralateral to the bowling arm (mean difference 4.9°, $p = 0.0039$) and ball release (mean difference 9.6 °, $p = 0.002$). Which has previously been shown to place significant stress on the lumbar spine and has been associated with the increased incidence of low back injury in this population (Crewe et al., 2013; Ranson et al., 2008). Additionally, in the musculoskeletal tests performed, the injured group had a significantly decreased hold time in the Biering-Sorensen test (Biering-Sorensen, 1984), which is a test of trunk muscular endurance and therefore suggests a lack of muscular endurance of the back extensors. This reduced back extensor endurance may explain why they are more laterally flexed during the delivery stride compared to the uninjured group.

Back extensor strength is an important physical requirement to the fast bowler as the extensors of the back such as the erector spinae, quadratus lumborum and multifidus assist in maintaining a more vertical spine during the bowling action, specifically at back and front foot contact (Johnstone et al., 2014). As a result, strength and conditioning coaches could introduce the use of the Biering-Sorensen test (Biering-Sorensen, 1984) to screen FB's for low back injury risk and programme accordingly. This should improve dynamic control of the trunk and pelvis, increasing the FB's ability to maintain key positions throughout their delivery action. Furthermore, the injured group from the study by Bayne and associates (2016) demonstrated increased knee valgus angle during lumbo-pelvic control during unilateral tasks (single leg decline squat). This increased knee valgus angle may also have increased lateral flexion of the trunk during the delivery stride due to reduced lumbo-pelvic control. With an increase in increase in Increased lateral flexion of the trunk being previously identified as a potential cause of lumbar spine injuries (Glazier 2010). To outline, Glazier (2010) discussed potential considerations in the aetiology of lumbar spine pathology in cricket FB's and suggested the 'crunch factor', which is defined as the instantaneous product of lateral flexion and axial rotational velocity of the lumbar spine, as a potential cause of lumbar spine injuries. This finding by Glazier (2010) demonstrates the significance of core and unilateral based exercises within a fast-bowling strength and conditioning programme, as it can in the increase of lower back muscular endurance and enhance lumbo-pelvic control during unilateral tasks and therefore reduce the risk of injury (Bayne et al., 2016). These findings agree with results reported in Forrest and colleagues 2017 review of literature on the risk factors for non-contact injuries in adolescent FB’s. From the research reviewed Bayne et al. (2016) identified excessive lateral trunk flexion while bowling, reduced trunk extensor endurance, and poor lumbo-pelvic control as being modifiable risk factors for non-contact injuries in adolescent FB’s. Recently, Keylock et al. (2022), investigated the incidence and prevalence of lumbar bone stress injuries (LBSI) in adolescent fast bowlers over one year. Additionally, the study also aimed to identify risk factors for LBSI in adolescent fast bowlers. They found injured adolescent fast bowlers had non-significantly less hip internal rotation compared to uninjured bowlers. This may result in different bowling kinematics that increase the risk of lumbar bone stress injuries (LBSI) through increased strain in the lumbar spine. Reduced hip internal rotation may be related to poor lumbo-pelvic-femoral control, which has been implicated in the aetiology of LBSI (Bayne et al., 2016). This suggests that further investigation is needed to identify how hip flexibility affects kinematics of the lumbo-pelvic-hip complex during the bowling action.

Another key area in injury prevention and management is the tracking and recording of bowling workload. Bowling workload is often used by skills coaches and strength and conditioning coaches to identify acute/chronic spikes in workload and inform physical preparation programming (Always et al., 2019). Various methods have been used, such as number of balls bowled per training session/match play, bowling intensity and actual/perceived intensity. Several studies (Alway et al., 2019; Stronach et al., 2014) have identified acute spikes in workloads as being associated with increased incidence and prevalence of LBI. Alway and colleagues (2019) examined the incidence and prevalence of LSF in professional FB's spanning a 7-year period. They found for this cohort (United Kingdom based) the risk of LSF is greatest in those aged 18-22, with-incidence of LSF increasing in July and September. This timeframe coincides with the UK cricket season and a condensed playing and training schedule at the beginning and end of the season. They also found bowling more than 234 deliveries in a 7-day period is a significant risk factor to LSF, when compared to those bowling less than 197 deliveries. A potential reason for younger FB spines being at risk from increased workload is they that have not achieved the necessary bone resilience to cope with the repetitive loading that occurs during fast bowling. This combined with the multi-planar trunk movements, places high torsional forces on the spine (Hind et al., 2016). This is a phenomenon which could potentially make younger FB's more susceptible to injury due to the repetitive loading to the spine during bowling (Arnold et al., 2017; Duggleby & Kumar, 1997). Furthermore, under-bowling, which refers to an insufficient number of balls being bowled by bowler, has also been shown to increase the risk of injury due to optimal anatomical changes not occurring in the musculoskeletal system (Hulin et al., 2014). Therefore, a sufficient bowling workload can be seen to function as a protective mechanism to the FB, which as stated in the SAID principle (specific adaptations to imposed demands) will allow for adaptations to take place (Sheppard, & Triplett, 2016). Furthermore, bowling load should be tracked throughout the season to identify any acute spikes in number of balls bowled within an agreed time frame which has been shown to cause and increase risk of sustaining a lumbar injury. To keep track of bowling load, strength and conditioning coaches should monitor on a weekly/monthly basis to identify acute/chronic bowling loads and programme gym-based workload appropriately to support performance and reduce the risk of injury. Finally, the evidence (Alway et al., 2019; Orchard et al., 2016) for lumbar injuries caused by overuse e.g., bowling load is growing and requires further attention. In particular, the need for evidence-based bowling load guidelines that not only track the number of balls bowled but also the intensity of each ball bowled.

Coaching and Skills

Thus far, the review has offered a broad understanding of the physical and technical requirements of fast bowling in the hope of better understanding the requirements underpinning a training model for adolescent fast bowlers. The following section will discuss the skill development component from the perspective of the coach. There is a paucity of research that has been conducted in the coaching of adolescent/developing FB's. Several studies have investigated what key components are needed by coaches and elite current and or former players to develop FB's. Phillips et al. (2010a) conducted a qualitative study where eleven past or present Australian elite FB's were interviewed on the components needed for the acquisition of expertise and performance development in fast bowling. Data analysis revealed several emergent themes such as support networks, senior teammates, competition, coaching and individual learning as being important considerations. The participants identified the lack of formal coaching at an early age as being important. They felt this enabled their skills to emerge through discovery learning rather than over-prescriptive coaching, allowing them to learn and develop their own technique whilst not being directed to bowl a certain way. This highlights the importance of unstructured learning to optimise the learning process at an early age. Whilst these results add to the growing body of literature, it is important to acknowledge that modern cricket development programmes are more organised and structured, with regional and national youth pathways forming a significant part of the cricket development environment (English et al., 2018). There may therefore be less opportunity for FB's to develop in such a way. In a similar study to their previous paper (Phillips et al., 2010a), Phillips et al. (2014b) set out to investigate the experiential knowledge of elite coaches and FB's to reveal insights into expertise acquisition in cricket fast bowling. Through one-on-one interviews experts suggested several factors that comprise expert performance and talent in fast bowling. Psychological factors such as motivation, mental strength, competitiveness, work ethic and positive attitude were seen as vital for success, as these psychological skills allow the fast bowler to cope with the metal pressures of bowling. Although, various skill and physical attributes such as lever length, muscle strength, flexibility, coordination, and ball release height can generate ball velocity, the experiential knowledge of experts acknowledges that individual differences do exist in the ability to create pace. For example, height has been identified as a key attribute for creating bounce, with taller bowlers being perceived to create more bounce of the crease (Stuelcken et al., 2007). Although described as useful, they are not an essential part of the bowler's armoury (Stuelcken et al., 2007). While not a primary focus of this review, recently, researchers have shown an increased interest in experiential knowledge regarding player development, training task design and talent development environments. In one such study Lascu and colleagues (2021) explored the female perspectives of talent development in cricket. Sixteen elite female athletes and seven cricket coaches took part in semi-structured interviews to draw from their experiential knowledge regarding player development, training task design and talent development environments. Researchers used a combination of inductive and deductive analysis to produce hierarchical emergent themes namely socio-developmental experiences, talent development environments and task design. All athletes interviewed identified unstructured play at an early age with older siblings as being beneficial for developing problem skills during play. This finding is similar with that of Phillips et al. (2014a) whose participants also identified a lack of formal coaching at an early age enabling skills to develop through discovery learning rather than over prescriptive coaching.

Summary

Research into the physical and physiological attributes associated with fast bowling has expanded over the last decade and led to a greater understanding of the key technical requirements of bowling. This has allowed strength and conditioning coaches to work with skills-based coaches to prevent/reduce injuries and enhance performance. However, further research is needed on the physical and physiological demands experienced by the adolescent fast bowler. As stated previously, adolescents develop physically at varying rates during adolescence (Lloyd et al., 2014), which can leave them more prone than adult fast bowlers to over-use injuries, back/trunk injuries, and growth-related injuries such as Osgood-Schlatter disease in the lower extremities (Stretch 2014). Further research in this population, would be beneficial from a physical preparation and injury prevention perspective.

From the evidence available, FB’s have a leaner total body composition when compared to similar sports projectile sports such as baseball and javelin (Carvajal et al., 2009) as well as having a larger physical stature, increased strength levels and leaner upper torso leading to FB’s generally having a higher ball release velocity than their smaller and less lean counterparts. Conflicting reports on other attributes, such as total limb length and shoulder to wrist length have been shown in some cases to have strong correlations with ball release speed, however, some have shown that limb length did not contribute to ball release speed. Taken together, these results suggest total limb length and shoulder to wrist length may be best used as a non-modifiable talent identification tool by skills coaches rather than a performance outcome measure. Additionally, fast bowling is an intermittent high-intensity activity which is largely fuelled anaerobically, that also consists of prolonged periods of low-intensity activity during non-bowling activities. Therefore, fast bowlers have been highlighted to require a well-developed metabolic system to cope with the aerobic/anaerobic demands across the differing formats of cricket. This requirement should be a key consideration for strength and conditioning coaches when designing training programmes for physical performance for FB's, which should, in theory, optimise physical performance. Fast bowling is not dependent on one single physical variable, but the evidence indicates that strength and conditioning coaches should design progressive periodised programmes to increase strength in the upper-body to assist with bowling and lower-body which needs to withstand the repeated muscular work during back/front foot impact. Eccentric muscle strength could be seen as a key factor from a physical and technical standpoint e.g., maintaining an extended knee during FFC and assist in withstanding GRF that occur during FFC which will allow for a better transfer of kinetic energy through the body (Johnstone et al., 2014). From an injury prevention/reduction standpoint the evidence suggests that low back injuries are highest amongst fast bowling populations with bowling action and bowling load being cited as the major causes. Strength and conditioning coaches need to be aware of the relationship between the different bowling actions (mixed specifically) and low back injuries, which place additional stress on the body and how this will impact the amount and type of physical conditioning that is undertaken with bowlers who use this action.

Over the course of the literature review, areas of importance to a strength and conditioning coach from a physical and technical point of view have been covered. Additionally, different areas of research such as the physical and physiological demands, injuries and injury risks and well as methods that can be used and mitigate injuries e.g., bowling workload monitoring. This has formed the basis of the physical, technical and psychological requirements of fast bowling. Therefore, the aim of the study is to explore the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowler and to determine the effects of a physical preparation programme on developing adolescent fast bowlers.

Methods

Part 1

Participants

The sample consisted of 6 international male fast bowling coaches who had playing and coaching experience ranging from 6 years to 29 (averaging 19.8). In order to gain a broad and balanced overview of fast bowling skill, participants were purposefully selected to provide a rich representative sample. All participants had a cricket specific coaching qualification with two coaches being qualified at England Cricket Board (ECB) level 4 (the most advanced in the United Kingdom), two being qualified at ECB level 3 but currently undergoing the ECB level 4 award, 1 being qualified at level 3 qualified in New Zealand which is the equivalent of ECB level 4 award and 1 coach having a UKCC level 3 coaching award. At the time of the interview participant backgrounds included national level male fast bowling coaches (*n*=3), national academy level male/female fast bowling coaches (*n*=2) and university level fast bowling coach (*n*=1). All participants were actively coaching in male and female cricketing environments across academy and senior levels in Scotland and England and were recruited through Cricket Scotland coaching network by invitation. It was hoped that this cohorts vast experience across multiple environments in elite youth and adult populations would assist the researcher in answering the research question.

Design

A qualitative methodological approach was chosen to explore the perceptions of elite level international fast bowling coaches to determine, not only what technical, physical, and psychological skills are required to be a successful adolescent fast bowler, but to focus on the optimal support mechanisms that surround and drive this process. Participating coaches were required to describe their coaching practices and experiences and provide detail of their knowledge and understanding of the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowler. Due to the subjective nature of the skill, the construction of the interview script undertook a process. This process involved the use of four Scottish national-level coaches who have experience of coaching fast bowlers who assisted in the design and testing of the questions. Once the pilot study was completed, questions were refined to reduce the risk of ambiguity. This process ensured questions were specific to the skill of fast bowling The four coaches involved in the pilot study were excluded from taking part in the next stage of qualitative data collection. The final interview script comprised of 11 targeted questions (Table 1). Each question within the interview script had additional prompts and probes which allowed the interviewer to extract additional information from the interviewees, The researcher maintained a neutral and impartial stance during prompting and probing in order to build a rapport and maximise the opportunity to enable open responses from each participant (Thomas & Magilvy, 2011).

All interviews were recorded and transcribed verbatim prior to analysis, with interviews lasting no longer than 60 minutes each. Finally, member-checking was completed by asking all participants to review transcribed interview scripts to confirm they were an accurate representation of their interview experience (Punch 2005).

Table 1.

Questions relating to the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowler.

Main Question	Prompt	Probes
Background Information		
Q1. Could you describe your involvement in coaching cricket?	• Number of years • Current place of coaching • Coaching qualifications • Countries you have coached • Male/Female • Age groups	Do you feel qualifications are important for knowledge development? How do you keep your coaching skills current? Do you to part in continued professional development?
Physical (anthropometry and body composition)		
Q2. What physical attributes does a fast bowler require to bowl fast?	• Height • Body mass • Limb length	Which of those attributes is the most important? And why? Does maturation stage impact this? And why?
Q3. What are the physiological	• Strength/Power • Cardiovascular endurance	What structures are in place to support

attributes required to be a fast bowler?	• Muscular endurance? • Speed • Flexibility/mobility	physiological/physical development? Is this promoted in the programme/sessions? And why? Can physiological/physical deficiencies be a barrier to player development? And why?
Q4. Do you implement physical preparation into your coaching programme?	• How long • Type • Duration	What is involved? Within coaching sessions? And why? Out-with coaching session? And why? Delivered by who?
Technical		
Q5. What is the process for identifying a developing fast bowler?	• Physical characteristics • Technical characteristics • Physiological characteristics • Psychological characteristics	When you identify a player and why? What criteria is selection based and why? Who is involved in this process?

Q6. Which of the key stages during fast bowling delivery are the most important to bowling fast (MPH)?	• Run up • Back foot contact/Front foot contact • Ball release speed • Ball release point • Follow through	Which of the key stages during fast bowling delivery are the most important to bowling fast? And why? How can these technical attributes be developed? Coaching? Maturation process?
Q7. What bowling action do you consider to be the most effective for bowling fast (MPH)?	• Side on • Front on semi-open/mid way • Mixed • Reasons	What is it about selected actions that assist in bowling fast? Hip angle? Shoulder angle? When would you change a players action? And why?
Psychological		
Q8. Describe any psychological attributes that are needed to be a fast bowler?	• Motivation • Coping strategies • Role of the coach • Sport psychologist support	Psychological skills training? Within skills sessions? Out-with skills sessions? Pre-practice game routines? Examples?
Q9. Describe how you decide on	• When • Criteria	Maturity? Psychological? Physiological

allowing a young fast bowler to bowl as fast as possible vs control?		Technical requirements?
Q10. Describe how support networks contribute to the development of a adolescent fast bowler?	• Parents • Teammates • Friends • Participating in other sports	Parents previous knowledge of sport? Parents providing travel to locations across the country? Competition with teammates? Support from friends not involved in sport?
Role of Strength and Conditioning		
Q11. Describe the role the strength and conditioning coach plays in the development of a fast bowler?	• Role of S&C Coach • Physical preparation • Programme support • Importance	Do you currently provide the S&C support? Why? Number of sessions per week/month? Player access? Do players value the addition of S&C as part of their development? Do you liaise with the S&C coach?

Procedure

To target coaches with the appropriate experience across multiple environments in elite youth and senior populations the researcher distributing the research study brief and consent forms throughout the Cricket Scotland coaching network. Prior to agreeing to take part in the study, all coaches were provided with a study brief, participant information sheet and informed consent sheet. Participants were advised by the researcher that they have the right to withdraw from the study at any time before the anonymising of the data, once the data has been anonymised, they may no longer be able to withdraw as their data will not be recognisable. Participants were also advised that they had the right not to answer any questions they did not wish to, and they would have access to the data for member checking after the interview. Once participants agreed to take part in the study, each completed an online scripted interview hosted on Microsoft Teams. The study was approved by the Research Ethics Committee at Edinburgh Napier University.

Data analysis

All interviews were recorded and transcribed verbatim prior to analysis. Following the initial reviewing of the transcribed interview responses, the data was analysed using a reflexive thematic analysis approach (Braun & Clarke, 2019), which follows a six-stage process: 1) familiarisation with the data set, 2) coding, 3) generating initial themes, 4) developing and reviewing themes, 5) refining, defining and naming themes, and 6) writing up. This method of thematic analysis has been used in previous strength and conditioning studies (Weldon et al., 2021).

During stage 1 and 2 a deductive approach was used to analyse data based on existing research and theory, which provided a lens through which to analyse and interpret data (Braun & Clark 2020). This meant exploring for evidence for themes highlighted in previous research (Phillips et al., 2014). During stage 3 an inductive/deductive approach what taken to analyse the data before finally, an inductive approach was taken in stages four and five.

Trustworthiness and Credibility

Several steps were taken to account for the credibility, transferability, dependability, and conformability of the data (English, 2017), as previously outlined in Denzin & Lincoln (1994). To achieve this, a triangulation technique (Patton, 1990) was implemented, which was used by the researchers to develop a richer understanding of the phenomena. Investigator triangulation was used to support the study by following the procedure outlined by Côté & Salmela (1994) and Weinberg & McDermott (2002). To begin the process of analysis the raw data was read, coded then analysed, after which, agreement was sought from the critical friend. The interviewer (researcher) was central to the deciding any discussions relating to the coding process, as they were able to provide additional dimensions and context having interviewed each participant (Weinberg & McDermott, 2002). Throughout this process and construction of themes, a second stage of review was completed by the critical friend. This process required independent checking and confirming patterns between the completed coding and category construction during theme formulation. Throughout the process the researcher and the critical friend held regular in-person and digital meetings during the deductive coding and inductive theme formation to discuss areas that may have been under or over developed and to remove any potential assumptions that may have been made from the gathered and coded information.

A critical friend with over 15 years of experience in qualitative research was used throughout the different stages of the data analysis. The critical friend was used to independently check the deductive and inductive stages of the data analysis process. Finally, member-checking was completed by asking all participants to review transcribed interview scripts to confirm they were an accurate representation of their interview experience (Punch 2005). This was done by contacting each participant coach and requesting them to confirm and agree with their transcribed interview script. Investigator triangulation was also conducted whereby, once the raw data was read, coded, and analysed the researcher met with the critical friend with a worked example (question 1). This involved reviewing each coaches transcribed interview script to generate codes that would later be developed into themes (Braun & Clark, 2020). Once the codes were generated the researcher and the critical friend wrote down codes by hand in written form to actively produce themes which were then compared. An example of this can be seen in Appendix C. During this stage both parties presented their initial themes and discussed the formulation of their themes after which an agreement was sought. This process of sense checking was consistent throughout the analysis and played a vital role in the formulation of themes.

The following section provides descriptive information detailing the methodological approach used for the training model intervention.

Part 2

For the second part of the study a 14-week experimental training programme was performed, based on previous interventions in adult (Mukandi et al., 2014) and adolescent populations (Pote et al., 2016) through the cricket off-season. All participants had not engaged in pace bowling for 2 months leading up to the study.

Participants

Six national level academy male adolescent developing fast bowlers were recruited for the investigation. The age, body mass, and resistance training age for each participant is shown in Table 2. Each participant who took part in the study bowled with their right arm. All procedures were approved by Edinburgh Napier University Ethics committee. A study brief (Appendix D) was provided to each participant and written informed consent (Appendix E) was obtained from each participant or parent/guardian prior to commencement of the investigation as well as a physical activity and readiness questionnaire (Appendix F).

Table 2.

Descriptive measurements for study participants.

	Bowlers (n = 6)
	Mean ± SD
Age (years)	18.1 ± 1.06
Height (cm)	183.16 ± 3.65
Body Mass (kg)	75.83 ± 4.87
Training age (years)	1.1 ± 0.71

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

Training programme

All participants followed the same strength and conditioning programme (SCP) which consisted of 2 gym-based sessions and 1 conditioning session per week on non-consecutive days during a total of 14 weeks (28 gym-based sessions and 14 conditioning-based sessions). An attendance record can be viewed in Appendix H. The SCP followed a multi-targeted block periodisation approach with the view of developing multiple physical and physiological adaptations such as muscular strength, power, aerobic endurance and anaerobic capacity (Issurin, 2008; Suchomel et al., 2018), 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 (Suchomel et al., 2018). 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) (Fisher et al., 2013: Nimphius et al., 2012), core strength variations (e.g., front and side plank) (Bayne et al., 2016) and eccentric capacity (bilateral box jumps) (Weldon, 2020). All selected exercises were based on previous research (Callaghan et al., 2021, Fisher et al., 2013, Mukandi et al., 2014, Nimphius et al., 2012 and Suchomel et al., 2018) 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 G.

Procedures

The studies physical testing procedures were split into two sessions over a 4-day period. To optimise validity and reliability subjects completed the tests in s specific order using a standardised warm up for each and recognised testing protocols. Session 1 testing was performed in the following order: 3RM bench press, 3RM hex bar deadlift, 3RM bent over row and horizontal pull, with session 2 performed (72hrs later) in the following order: counter-movement jump and Yo-Yo Level 1. Participants were provided with clear instructions on how to perform each test, with no encouragement provided. Participants were requested to refrain from strenuous activity for 48 hours and arrive in a hydrated state.

Strength test (3RM).

Upper and lower-body tests consisting of Bench Press, Hex Bar Deadlift, Bent Over Row and Horizontal Pull were included as a measure of pushing and pulling strength. Testing was performed within a single one hour and thirty-minute session. Each participant warmed up by selecting a load that allowed them to complete 5-10reps before taking a 1-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. Each participant then took a 2-minute rest before completing a near maximal load for 3 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. Weight was increased or decreased until 3RM with correct technique was established (McGuigan, 2016). Participants 3RM had to be confirmed within five testing sets.

Horizontal pull up test

After a 5-minute break each participant completed the final test of this session. The horizontal pull up test was to measure the participants upper body strength and endurance abilities (Sinclair et al., 2021). A weightlifting barbell was placed in the squat rack at a height whereby 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 bent at a 90 angle. Each participant then lifted their hips, so their body was straight, and their elbows were fully extended. They were instructed to pull their body towards the bar until the bar touched mid-chest (nipple line) then lower themselves back to the start position. This sequence was repeated until they could not pull themselves up to where the mid-chest touched the bar as described above. The number of repetitions were recorded by the researcher

Counter-movement jump

Each participant performed a standardised warm up prior to the test then was asked to stand between two sticks which projected an infrared beam (Microgate, Bolazano, Italy). They were instructed to place their hands on their hips before performing a counter-movement action by flexing the knees and hip before forcibly extending ankle, knee, and hip joints to jump into the air. Participants were instructed that their knees must remain extended during flight time (McGuigan, 2016). Each participant had 3 attempts with best attempt being recorded as the score, each attempt was separated by 2 minutes rest. Counter-movement depth was standardised for all participants by ensuring they lowered to a semi-squat position (Webster et al., 2020). Excellent reliability values for counter-movement jump in cricketers has been reported previously by Carr et al. (2013), with an interclass coefficient (ICC) of 0.987cm and SEM of 0.6cm.

20m sprint test

After 5 minutes of passive recovery after the counter-movement jump test participants completed the 20m sprint test for assessment of acceleration speed. 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 3 (McGuigan, 2016). Each participant had 3 attempts with their best attempt recorded as the score, each attempt was separated by 3 minutes. Before the test, participants completed a sprint warm-up that 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. Appropriate levels of reliability for 20-m sprint test have been reported by Locke et al. (2013), with an ICC of 0.96, SEM of 0.06 seconds, and smallest worthwhile change of 0.09 seconds. Additionally, the 20m sprint test has been used previously in cricketing club-standard populations (Feros et al., 2019).

Yo-Yo Level 1 Intermittent Recovery Test

Yo-Yo level 1 test was used to measure participants ability to repeatedly perform high-intensity aerobic work and was conducted 72 hours after the previous gym-based tests. 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 an 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 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. Participants continued for as long as they could maintain their speed with audio signals. Test was terminated when any participant could no longer maintain speed for two trials (McGuigan, 2016). A warning signal was given the first time they do not reach the turning or start line. After completion of Yo-Yo level 1 test each participants distances were individualised and set based off their completed level as seen in a previous study by Herridge et al. (2017).

Bowling Protocol

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 (Faber et al., 2016; Callaghan et al., 2019). 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 (Nalepa and Gwiazda, 2020).

As previously outlined by Faber and colleagues (2016) 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.

Data recording was carried out using the 17 MTx IMU's measuring 38mm x 53mm x 21mm and weighing 30gs (XSENS technology, Enschede, The Netherlands). Each IMU includes a 16-bit triaxial accelerometer, a gyroscope; a magnetometer, all attached via daisy chain sequence to a XBus master unit, and a battery pack situated within the posterior part of the MVN Biomech suit (XSENS technology, Enschede, The Netherlands). The range of the accelerometer was set to ± 18g, the gyroscope was set to ±1200°.sec^{-1} and the magnetometer measured in the range of ± 750m Gauss (XSens, 2012). The sensors were positioned with the x-, y- and z-axes corresponding to anteroposterior, longitudinal and mediolateral axes of rotation according to the local coordinate frame (XSens, 2012).

Bowling test.

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 (Callaghan et al., 2020). 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 analysis

Descriptive statistics for physical qualities (Table 3) were presented as mean ± standard deviations to describe each variable. Mean difference and 95% confidence limits (CL) were also established between pre- and post-test measures. Paired sampled samples t-test to establish changes between pre and post testing measures. Due to this statistical approach and 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 (Cohen, 1992; Middleton et al., 2016). Statistical tests for upper arm peak angular velocity were conducted using Graph Pad version 9.4.1(Prism - GraphPad, n.d.). A Mixed Model 2-Way ANOVA was used to establish changes pre- and post-testing (Table 4). Within participant group there was no significant difference ($p = 0.77$) in upper arm angular velocity.

Part 1

The following results and discussion section provides an overview of the qualitative component of the study (part 1).

Following analysis eleven themes of significance emerged 1) Developing Knowledge and Expertise, 2) Physical Attributes and Stature, 3) Physical qualities, 4) Physical preparation, 5) Criteria for identification, 6) Bowling action stage, 7) Effective action 8) Psychological attributes needed to be a successful fast bowler, 9) Bowling fast vs control, 10) Support networks for a developing fast bowler and 11) Role of strength and conditioning coach. During the formulation of themes, sub-themes of importance emerged, twenty-four in total and are described within each theme section below.

Theme 1- Developing knowledge and expertise

Theme 1 describes the coaches playing and coaching experience and contains two sub-themes; i) Formal learning and ii) Informal learning.

Sub-theme i – Formal learning

All coaches explained the importance of formal coach education to developing their knowledge and expertise of coaching fast bowlers (theme 1).

Coach 2 states the importance of coaching qualifications to coaching practice.

'…*and yeah I mean 100% UM coaching qualifications are important…' (coach 2)*

Of this, three of the six coaches identified how formal coach education improved their communication skills and assisted them when interacting with players during coaching sessions (sub-theme i). Coach 6 describes this aspect in more detail.

‘I mean the they [course/s] just give you a good foundation because you know being an ex player you kind of know how it feels for you, but not necessarily getting across that information for other players, and I think the coaching courses that have been on allow me to get that information and this is your information across well, to the players I’m coaching, basically’. (coach 6)

Two of the six coaches felt the benefits of some qualifications/courses could be tick box exercise, as well as getting caught up in just completing qualifications/courses. Additionally, they felt the benefits of completing the qualification/courses came down to the competence of the tutor. Coach 4 confirms below.

‘Not just sitting in a classroom in in completing tick box exercise with a bit of coach education can be, on top of that...’ (coach 4)

‘Yeah, and I think. I think we get caught. It's an interesting thing, isn't it? Because I think we get caught up a little bit in the numbers…’ (coach 4)

Sub-theme ii – Informal learning and networking

In conjunction with all the benefits all the coaches perceived to be associated with formal learning, three of the six coaches considered informal continual coach development to be of equal importance. For example, Coach 1 and Coach 6 emphasised aspects of informal learning such as networking during courses and conversing with other coaches during training sessions and match days as being beneficial to their ongoing coaching development.

‘Yeah, so not so much in terms of continued professional development for coaching I don't do much along those lines other than watch cricket and talk to other coaches but as I suppose nothing formalized…’ (coach 6)

“I think I picked up a reasonable amount knowledge just from playing the game and being around the game for a long time so rather than the two days at Loughborough that, you do that. That doesn't give me a massive amount of knowledge to take away...” (coach 1)

Theme 2 – Physical attributes and stature

Theme 2 provides evidence relating to coaches’ perceptions of the required physical attributes required to bowl fast and contains two sub-themes, i) No ‘one size fits all’, and ii) Height and limb lengths.

Sub-theme i – No ‘one size fits all’

Five out of six coaches explained there is no ‘one size that fits all’ when describing the physical attributes of fast bowlers. For example, Coach 2 stated there are no set rules on the required physical attributes for fast bowling due to individual variation.

‘I don't think there's any hard and fast set rules to be honest. You get tall, gangly, loose limbed fast bowlers and you also get short stocky. Uhm, more in inverted commas

power based fast bowlers. So I don't think there's a there's a definitive answer to that. I think athleticism is important, UM, power and strength are important, but in terms of body shape and height, I don't think necessarily, there's any hard and hard and fast rules, although you know having height does give you some advantages in terms of bounce and that type of thing, but being shorter sometimes helps fast bowlers to build better yorker's and so it's just different trajectories that you get from height rather than necessarily.' (coach 2)

Sub-theme ii – Height and limb lengths

Three of the six coaches stated longer and taller is better when outlining their ideal anthropometrical model for a successful fast bowler. For example, Coach 5 describes that although height used to be perceived as being beneficial, there are several examples of successful fast bowlers who were short and smaller in stature.

'Height used to be a thing, you know. I mean, there was a guy called Malcolm Marshall played for the West Indies many years ago. He was small in stature and then you had guys like Darren Gough who also was the one small in stature. I don't think there's one sort of size…' (coach5)

Theme 3 – Physical qualities

This theme provides evidence relating to the physical qualities needed for successful fast bowling and contains three sub-themes, i) Importance of strength, ii) Importance of power, and iii) Cardiovascular endurance.

Sub-theme i – Importance of strength

Six out of six coaches expressed the importance of fast bowlers requiring appropriate levels of strength to be a successful fast bowler. Coach 6 and Coach 2 outline their thoughts below.

'The strength aspect is as important, it's just going to allow the body to withstand so much more of the pressure.' (coach 6)

'You know, you get fast bowlers who can bowl fast for a couple of weeks, but they're not strong enough or flexible enough so they get injured.' (coach 2)

Sub-theme ii – Importance of power

Four of six coaches described the importance of power for successful fast bowling, with one coach identifying both power (Coach 4) and strength as being important.

Coach 1 contextualises this point based on his own playing experience.

'Uh, my strength, I don't think, you need to be strong to be able to bowl fast. I think you need to be strong to be able to stay fit like I'm looking at my own history. I was never express but I could bowl 85 miles an hour, but then two weeks later I've been sat on the physical bench again. So the way I personally look at it now is you need a level of strength to keep you on the pitch…' (coach 1)

Coach 4 goes further and describes a combination of strength and power needed for successful fast bowling.

'…strength, I think power is, it's definitely a combination of those two and you don't see many guys being able to walk up to the crease and then ping the ball down really quickly or you know the forces that generate on their body and you know they have.' (coach 4)

Sub-theme iii – Cardiovascular endurance

Three out of six coaches identified cardiovascular endurance as being an important physical quality for successful fast bowling with a lack of cardiovascular endurance being detrimental to bowling performance.

Coach 5 describes how cardiovascular endurance levels need to be high and the effects of lower levels of cardiovascular endurance have on bowling performance.

'I think a cardiovascular level have to be high and one of the things that first goes out the window is people ability to get to the crease. You know physically, physically, they're not like cardiovascular levels are low and they just don't have that physical fitness to get to the crease, you know ball after ball after ball, so the so the pace of the approach diminishes quite quickly because they're not cardiovasculary fit.' (coach 5)

Coach 1 reiterates coach 5's opinion on the importance of cardiovascular endurance then relates to statistics around test bowlers.

'Yeah, good cardiovascular. I think you need to be able to, uh, have good endurance and run for a good while. If you look at the stats based around test bowlers and the distances they cover during a game, you need to be physically aerobically.' (coach 1)

Theme 4 - Physical preparation

Theme 4 describes the provision of physical preparation for fast bowlers within the cricket coaching programme with the emergence of three sub-themes of significance, namely i) Provider of physical preparation, ii) Types of physical preparation, and iii) Physical preparation tools.

Sub-theme i – Provider of physical preparation

Six out of six coaches implemented physical preparation into their coaching and/or skills programmes. Five of the six coaches provided physical preparation within their coaching/skills sessions. Coach 4 describes the benefits of skills-led physical preparation.

“We got the coaches to add that into the sessions because they because they weren't getting additional strength and conditioning support, so we were trying to cover it in that sense.’ (coach 4)

Sub-theme ii – Types of physical preparation

Four of the six coaches state they use the warm-up as a method of developing fast bowler technique and mentally prepare players prior to skills based activities. Coach 6 provides examples of the types of physical preparation that is provided to fast bowlers:

‘…specific mobility activation exercises just, parts before they go out to training before they go out to bowl in a match and it's more of a case of, I guess, that neurological activation. You know, it only takes like you know 3-4 minutes of doing that. Waking up that nervous system. I think that's important so and it's routine. That's the real important thing I think I'm making sure that yeah, the routine is there of and the player doing it and being consistent with it.’ (coach 6)

Sub-theme iii – Physical preparation tools

Coaches described the use of physical preparation tools such as hurdles, heavy ball, resistance bands and ladders within their coaching sessions, with three of the six identifying medicine balls and resistance bands being used to develop different bowling techniques. For example, Coach 4 describes resistance tools he used with sessions.

‘Med ball, resistance bands, so anything that would be classed as a constraint to help develop Uh, aspects of the technique.’ (coach 4)

Theme 5 – Criteria for identification

Theme 5 describes the coaches' criteria for identifying a developing fast bowler and contains three sub-themes, namely, i) Player mentality and drive, ii) Current technical and/or physical attributes and iii) Current bowling speed.

Sub-theme i – Player mentality and drive

Four out of six coaches identified player mental drive as being an attribute they look for in a developing fast bowler. Coach 5 states players must want to bowl fast to be a successful fast bowler,

'…but If they don't want to bowl fast and then you're not going to get quicker. I think you need all of the above where you said it's very simple paraphrase and I don't want to cut shortly, but I think you need an element of all of those to get a genuine fast bowler who wants to run in and do the hard work fast. Bowling is fun, but it's bloody hard work and its not for everyone.' (coach 1)

Coach 6 reiterates a similar point to Coach 5.

'…but eagerness that come with a player to want to bowl fast and want to be a fast bowler. So, I think first and foremost, it comes from, yeah that players enjoy and want to play cricket and want to be a fast bowler. So that's really important. If you don't have that and then it's very tough to develop a fast bowler if they don't want to bowl fast.' (coach 6)

Sub-theme ii – Current technical and/or physical attributes

Three of the six coaches interviewed identified a player's current technical and physical attributes as an initial criterion that they used for identifying a developing fast bowler. Coach 2 makes specific mention to first looking at the technical and physical aspect of a developing fast bowler.

‘The first thing probably you see is the technical and physical aspect, I suppose.’ (coach 2)

Coach 5 echoes Coach 2’s comments and confirm that the physical and technical things are important criteria for identifying a developing fast bowler.

‘There's sort of the physical and technical things and sort of the technical things of how they bowl. You know the how the bowler approaches the crease and how it delivers it.’ (coach 5)

Sub-theme iii – Current bowling speed

Three of the six coaches identified current bowling speed as being an important criterion with Coach 5 expressing a level of excitement when initially viewing a developing fast bowler bowling fast.

‘You look at someone you go that boy can bowl fast. There's obviously the obvious thing about the ball going down quickly.’ (coach 5)

Coach 2 raises a similar point on the developing fast bowlers bowling speed and how they are releasing the ball as being the first thing they would look for.

‘So, if you're looking at a 14-15/16 year old group and you're looking for a fast bowler then it would be the speed if you're looking at in bowling it would be speeds that they were letting the ball go after the run, up would be the first and foremost thing you you'd look for, if specifically, you were looking specifically for a fast bowler.’ (coach 2)

Theme 6 – Bowling action stages

Three distinct stages of the bowling action were identified as key to a fast bowler’s ability to bowl fast and emerged as three sub-themes, namely, i) Strong position at back and front foot contact and braced front leg, ii) Run-up, and iii) Hip and pelvis separation.

Sub-theme i - Strong position at back and front foot contact and braced front leg

Six out of six coaches outlined the importance the key positions needed at back and front foot contact and a braced front leg. Coach 6 describes the position of the back foot at the point of ball release and being strong through the front foot but not braced.

‘I would want there to be back foot contact at the point of release and I would say that that's even with being strong through your front foot, not braced.’ (coach 6)

Coach 2 adds to Coach 6’s point on whether or not a braced front is a requirement to bowl fast by discussing it in the context of the coaching model.

‘So, I mean, yeah, so taking brace front leg. So the coaching model would say to bowl fast you really want a brace front leg, but I could tell you any number of bowlers who can bowl 90 miles an hour with a bent front leg so yeah.’ (coach 2)

Coach 1 describes the importance of being strong through crease when bowling and discussing the concept of bracing the front leg on front foot contact.

‘You need to be strong through the crease and there's a big talk at the moment about bracing your front leg. Uhm, I don't disagree with that as a concept, I don't think it's the be all and end all, Uhm, to being a good fast bowler. What I do think it does is it reduces how much pace you lose right? Rather than making you bowl quicker, it just reduces how much pace you lose, so you can brace out your front leg you'll retain more pace that you've naturally got and then the follow through good again. If you can finish off your action stronger, you'll most probably pull another mile or two out of it.’ (coach 1)

Sub-theme ii – Run-up

Five of the six coaches identified the run-up phase as being important factor for maintaining momentum and assisting ball speed. Coach 3 describes the impact run-up has on ball release speed.

'… some of the most important areas are the run up. For lots of people that provides a significant amount of ball release speed, you know from what I've read and from what I've seen, it can contribute up to like 30% in ball release speed in some individuals.' (coach 3)

Coach 4 also confirms the importance the run-up can have on ball speed and continued momentum.

'So how we would assess that there would be your run up, I reckon about 30% of your final velocity potentially… And so the key thing about that though, is the continued momentum all the way through to the back foot impact.' (coach 4)

Sub-theme - iii Hip and shoulder separation

Two of the six coaches identified hip and shoulder separation and/or dissociation during the bowling action as being an important factor for bowling fast. For example, Coach 6 describes shoulder pelvic dissociation as being the second most important factor to bowling fast.

'Shoulder pelvic dissociation… would be combination of backfoot contact at point of release and strong front leg at point of release.' (coach 6)

Coach 3 outlines a similar point to coach 6's opinion on hip and shoulder separation.

'Hip-shoulder separation is probably the next biggest one you know probably, It makes up the majority of the rest of the speed Yeah, so allowing the hips to separate from the shoulders, creating a stretch for the big muscles of the body, you know that that often separates a lot of bowlers who bowl 70 miles an hour and those who bowl 85 is the ability to do that successfully.' (coach 3)

Theme 7 – Most effective bowling action for bowling fast

Within the theme of bowling action, two sub-themes of importance emerged, specifically, i) Side-on bowling action and ii) All actions have examples of fast bowlers bowling quick

Sub-theme i – side-on bowling action

Four out of six coaches identified the side-on bowling action as being the most effective for bowling fast. Coach 6 describes what he feels are the benefits of the side-on bowling action and relates his feelings back to his answer in an earlier theme.

‘It's either side on or three quarters more so than front on I just feel as if and because of that side on action you're able to get more of the pelvis and that shoulder, pelvic dissociation. …’ (coach 6)

Coach 3 further contextualises the benefits of a side-on bowling action by providing examples of previous fast bowlers and how this action was described in textbooks previously.

‘I think it's very difficult to give that answer if you look at if you look at history, a lot of the fastest bowlers ever, have been side on? You know Sean Tate, was side on Shoaib Akhtar was side on, Jeff Thompson was side on and Shabnam in the women’s environment is side on, you know or at least their back foot was side on at back foot contact, which is what kind of say you define it and whether that's just the result of the way that they were coached and you know the old-fashioned textbooks taught everyone to bowl side on cause that was the way’ (coach 3)

Sub-theme ii – all actions have examples of fast bowlers bowling quick

Four out of six coaches stated there are examples of fast bowlers who used one of the three actions who have bowled quick. Coach 5 states there is no one size or action that is required for a fast bowler to be quick.

‘So I would say there's no size, there's no one position that requires for that person to be quick, they're all different. And that's the simple answer. I mean, you could go through it and but I think people would see all those been. I don't know 10,000 fast bowlers that landed sideways on and only 3000 fast bowlers who have landed chest on, 2000 have landed, but to be honest, you can be more quick from any position, it's just that biomechanical efficiency and that physical attribute that person has got to do the ball quick, you know.’ (coach 5)

Coach 3 makes a similar point to Coach 5's reiterating that bowling quick is very much an individual thing.

'I think it very much depends on individuals though, like some people will have a natural preference to get side on or to get front on and just because you know potentially side on helps you bowl faster, doesn't mean that you change them to do that, you just have to work with individuals to figure out how to maximize their own physical abilities and their technical abilities…' (coach 3)

Theme 8 – The psychological requirements to be a successful developing fast bowler

Within this the theme of psychological requirements two sub-themes emerged from the analysis, namely, i) Bowler ego/aggression/motivation and ii) Bowler mental resilience

Sub-theme i - Bowler ego/aggression/motivation

Five out of six coaches described a developing fast bowler needing to have an ego, be aggressive when bowling and or being motivated to bowl quick and sustain this for extended periods of time. Coach 1 describes the importance of a fast bowler wanting to bowl quick and being almost narcissistic.

'I think you've got to be fairly narcissistic. You've got to back yourself to be able to do it . I think you've got to be fairly bloody minded that you're happy to just keep running in and bowling quick. It can be a nasty job if you're running in bowling, nasty bouncers and potentially hurting people. You've got to enjoy that side of the game. Its not always for everyone. I'm not saying at all fast bowlers are terrible human beings. But they've got to have an inner steel where they're happy to do that' (coach 1)

Sub-theme ii – Bowler mental resilience

Four out of the six coaches identified the importance of mental resilience to a developing fast bowler. Coach 4 describes the psychological challenges fast bowlers now face with the introduction of shorter formats of the game.

‘The game is changing a lot as well, so I think it's even tougher now for some of these guys playing in the T20 and number of games you know. The power and the strength elements have also been added to the batting stuff. So guys are now clearing the ropes quite easily with the with the bats they've got and I think you, you know and the other thing is one day you can have a great day and the next day can get in trouble, terrible day and then being able to bounce back from that and go again and go again and go again, I think it's so important.’ (coach 4)

Theme 9 – Bowling fast vs control in a developing fast bowler

This theme provides what coaches perceive to the criterion for allowing a developing fast bowler to bowl fast versus control and contains one sub-theme, i) Physical and emotional maturity.

Sub-theme i – Physical and emotional maturity

Five out of six coaches perceived physical and/or emotional maturity as being an important criterion for allowing a developing fast bowler to bowl fast versus control. For example, Coach 2 states if how he would encourage a bowler to bowl fast under certain parameters.

‘I think if you have a bowler who has the potential to bowl fast, you would always want to try and encourage them to bowl fast within the parameters of understanding that you still have to have some control with that, but you can work on that and also taking into account the safety aspect of it.’ (coach 2)

Theme 10 - Support networks for a developing fast bowler

This theme provided a backdrop of the contributing factors that assist a developing fast bowler and contains two sub-themes; i) Multi-sport participation and ii) Outlets from playing cricket.

Sub-theme i – Multi-sport participation

Four of the six coaches described the benefits of developing fast bowlers taking part in other sports and being a multi-sport athlete. For example, Coach 4 explains the importance of playing multiple sports and their positive influence on all-round athletic talent versus a player who has concentrated on a single sport.

'Yeah I would say, I would back myself 95% to be able to tell you having watched the game, whether some cricketer was played in different, another sport or not. And in the talent development environment anyway, yeah, cause you can just see the difference if you just play cricket. You're gonna be missing a few particularly athleticism.' (coach 4)

Coach 1 raises a similar point to Coach 4's feelings on the benefits of taking part in multiple sports all year around has on developing fast bowling talent:

'Again, all factors are involved, uhm, certainly the other sports side of things, if they're doing all the winter sports, that should keep them fit and strong, you would think, uh, I'm a big fan of cross platform sports.' (coach 1)

Sub-theme ii – Outlets from cricket

Two of the six coaches describe that due to the physical and mental demands of cricket, it was vital to have an outlet which was non-cricket related, thus acting as a distraction from the game and allow physical and metal recovery. Coach 4 describes how cricket cannot be the be all and end all.

‘The other thing about the game is it cannot be the be all and end on it can't be all the all-encompassing part of it. It's a long game of sport, right? You know crickets 7 hours a day, one day cricket. It's three hours for T20 and is 5 days for the Test match it takes up a lot of time and so it's important that you know the players have other things in their life to be able to be involved with to make sure that you know when they get in the paddock they're just enjoying what they do…’ (coach 4)

Theme 11 – The role of the strength and conditioning coach in the development of a developing fast bowler

This theme provides an overview of the coaches’ perceptions of the role the strength and conditioning coach plays in the development of a developing fast bowler and contains two sub-themes, i) Strength and conditioning coaches are vital to the development of a developing fast bowler and ii) Strength and conditioning coaches need to understand the technical requirements of fast bowling.

Sub-theme i - strength and conditioning coaches are vital to the development of a developing fast bowler

Six out of six coaches stated that strength and conditioning coaches played a vital part in the development of a developing fast bowler with Coach 5 best describing the role.

‘*We've touched on it, it has to be a sort of collaborative approach and it has to be a, you know, in conjunction with the coach and the player and they do play a vital part because I think that gives them longevity through time and you know it gives them that sort of ability to bowl fast consistently for a long period of time. And that's what goes into that to that program you know they offer a real support him by offering that consistent our program, a fast bowler and sort of physical preparation program,* *because they need to do that program and I'll keep saying to any young fast bowler you know you've bowled today, but go ahead and do your strength and conditioning program because that underpins everything else that you've done as well, because it just gives them that longevity you cannot ok, you can spot who isn't doing that preparation, the physical preparation, because then they fall away quickly and they don't have that longevity. (coach 5)*

Coach 3 reiterates Coach 5’s point and relates this back to his own playing career.

‘Again, thinking back to my own career, which I would then overlap into how I'm coaching now, I think the S&C is hugely important I think. A long term plan that you can work out with the bowler would set them up for five years. Uhm, I think you need to have both short term plans and long term plans for these young players so that they can achieve the best they can, cause I think I'm going back to my own playing days. There was a lot of short term plans and there were never any real long term right? This is what we want to achieve over a two year period of five year period. I think it's better now, because like I said, going back 25 years and I think because of the feelings that were happening.’ (coach 3)

Sub-theme ii - Strength & Conditioning coaches need to have a technical understanding of fast bowling

Three of six coaches stated strength and conditioning coaches need to have a technical understanding of fast bowling with coach 4 describing their feelings.

“Hugely important, yeah, and I think, it's important they start they understand the game in a little bit, you know and 'cause it is quite unique. Yeah, and there's unique elements to it. You do need to understand, the worst thing that happened to me is as a player I

feel is that when I was an institute athlete as I got, I just got treated like a rugby player. Yeah, now that's like sure.”

Coach 3 reiterates this point.

“it's a physical skill, and the technical depends on the physical. If you're not physically able to get into certain positions or manage the load in certain positions you're not going to be able to fulfil the skill without finding other compensatory ways of doing so. I think this it needs to physical coaches to have a real understanding of the art, and as we kind of spoke about earlier, not just providing generic programs to facilitate strength development.

Part 2

Table 3 below presents descriptive for the physical qualities pre and post training model.

Table 3.

Pre–post testing (mean ± standard deviation) and difference (mean difference ± 99% confidence intervals [CI]) results from 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 fast bowlers (n = 6).

Fitness test	Pre-testing (Mean ± SD)	Post-testing (Mean ± SD)	Mean difference	Percentage change	P value	ES	CI
CMJ (cm)	38.70 ± 3.56	39.31 ± 2.88	0.62	2	0.47	0.32	(L - 1.12, U 0.52)
20m (sec)	3.12 ± 0.05	2.93 ± 0.08	0.199	-6	.001	- 4.71	(L - 8.73, U -1.14)
Yo-Yo Level 1 (Lvl)	18.10 ± 1.92	18.65 ± 2.44	0.47	3	0.42	0.36	(L - 0.745, U 1.43)
Hex Bar Deadlift (kg)	116.50 ± 17.86	148.66 ± 29.02	32.2	28	0.006	1.86	(L .098, U 3.70)
Bench Press (kg)	61.66 ±14.02	75.83 ± 13.19	14.2	23	<.001	3.76	(L 0.82, U 7.04)
Bent Over Row (kg)	63.33 ± 12.11	81.33 ± 10.23	18.0	28	0.01	1.63	(L - 0.007, U 3.31)
Horizontal Pull Up (reps)	15.50 ± 2.07	22.50 ± 2.73	7	45	0.005	1.96	(L 0.14, U 3.86)

CM = centimetres; sec = seconds; Lvl = level; kg = kilograms; reps = repetitions; L = lower; U = upper

Table 4.

Pre-post testing results from bowling upper arm 6 over spell in adolescent fast 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	841.33	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 aims of the studies were to: Identify coaches' perceptions of the technical, physical, and psychological characteristics required for successful performance in adolescent FB's and develop and test an appropriate training model for fast bowling performance in cricket.

The main findings post 14-week intervention (part 2), showed group relative changes across all physical qualities with improvements in strength (+8%), power (+2%), muscular endurance (+45%), speed (-6%) and aerobic capacity (+3). These results (Table 3) 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 (Table 4). Additionally, these physical qualities (strength, power, muscular endurance, speed, and aerobic capacity) were perceived by the fast-bowling coaches (part 1) as being important to the developing fast bowler.

A 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 3). The ES in the present study was similar to previous findings (ES = 0.42) by Carr et al. (2015) 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 FB's (39.54 ± 3.35 cm) (Weldon et al., 2021). Bowling velocity has been strongly correlated (r = 0.74), with lower body power (Pyne et al., 2006). 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 ($p = 0.7769$) in upper arm angular velocity post 14-week intervention. As discussed previously, several coaches (four out of six) described the importance of power for successful fast bowling, with one coach stating a combination of power and strength is needed for successful fast bowling performance. This suggests that power is an important physical quality that can have a positive impact on fast bowling performance and should part of a developing FB's physical preparation programme (Herridge et al., 2017; Weldon et al., 2021). This improvement could be seen across all the participants lower-body power test scores which indicates a progressive periodised programme is an effective method for improving power.

A significant decrease 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, with a large ES (-4.71) present (Table 3), 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 (Herridge et al., 2017) . Additionally, mean scores were faster to that of international level FB's (3.14 ± 0.13) (Weldon et al., 2021) and comparable to that of elite English cricketers end of season 20m sprint times (3.05 ± 0.11 sec) (Carr et al., 2015) . A possible explanation for the differences in results maybe 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 (2021) 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 (Herridge et al., 2017) 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 (Herridge et al., 2017; Meyers et al., 2017) . These results support the coach's perceptions that sprint ability is important to maintaining momentum and assisting ball release speed (theme 6, sub-theme 2). This is consistent with findings by Philips et al. (2014) who also found run-up speed a key factor to successful fast bowling performance. Recently, Webster et al. (2020) showed a positive correlation between CMJ height and maximal running velocity ($p = -0.387$). A CMJ provides an indication of an athlete's slow stretch-shortening cycle ability (>0.25 seconds), which has been shown to be vital in initial accelerations during fielding tasks (Carr et al., 2015). FB's are required to cover short distances at maximal effort repeatedly throughout the game which is done by generating high velocities over the first few ground contacts (Carr et al., 2015; Johnstone & Ford, 2010). This was seen in the current study's mean decrease in participants 20m sprint times. Improving this physical quality can assist in coping with the movement demands of cricket and as well as adding to the FB's skill set. However, it should be noted any increase in the velocity of run-up speed will increase deceleration forces experienced at front foot contact, which could lead to an unwanted change in bowling technique (Stronach et al., 2014). As such, when trying to improve bowling run up speed, strength and conditioning coaches should design physical preparation programmes for FB's that increase lower body bilateral and unilateral strength and eccentric strength to ensure the FB can cope with the increased deceleration forces experienced at front foot contact. Additionally, increases in lower body eccentric strength will assist developing FB's in maintaining key positions during any technical adjustments to their action (Johnstone et al., 2014).

A non-significant increase in Yo-Yo 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) present (Table 3). The reported ES was similar to those of high-performance FB's previously conveyed by Weldon et al. (2021) (ES = 0.46) but lower than those reported in a study by Herridge et al. (2017) (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) (Herridge et al., 2017) and slightly higher than those (level 18.17 ± 0.88) in the recent study by Weldon et al. (2021). With FB's having been shown to cover the greatest distances and achieve the highest intensities within the cricket team (Petersen et al., 2010), it could be proposed that FB's who possess higher aerobic endurance may be better placed to cope with the match demands. This has been recently reported by

Webster and colleagues (2020), who showed a positive relationship between tests of physical qualities and physical match demands in 50-over cricket. These results were supported by three of the six coaches (theme 3, sub-theme 3), who indicated aerobic endurance was a requirement for successful fast bowling performance, with one coach stating that a fast bowler will not be able to get to the crease ball after ball if they do not have cardiovascular fitness. 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 3). Previous studies (Loram et al., 2005; Portus et al., 2000; Pyne et al., 2006; Wormgoor et al., 2010) have demonstrated a relationship between a more extended knee (>150°) during ball release and increased delivery speeds, while King et al. (2016) 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 (Portus et al., 2000). 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 (Elliott, 2000). This is of particular importance within adolescent FB’s, who are vulnerable to several different injuries during developmental growth. For example, adolescents have immature articular cartilage susceptible to micro-damage, partially ossified lumbar vertebrae, elastic intervertebral disks, and elongated musculo-tendinous tissues (Cyron & Hutton, 1978; Difiori et al., 2014). Therefore, age specific programmes, that are progressive and supervised are crucial in developing fast bowlers. Lower-body strength was a physical quality six out of six coaches (theme 6, sub-theme1) identified as being a requirement to successful fast bowling performance, with one coach indicating the importance of being strong at the crease during back foot and front foot contact to maintain effective bowling positions throughout the bowling action. As stated by the coaches, increased levels of relative strength, should allow the fast bowler to maintain the key positions required throughout the bowling action which in theory should allow them to bowl for long periods and increase the opportunity of taking wickets. However, coaches understanding of strength was based on their experiences from playing e.g., feeling strong. Although lower-body strength has previously been shown to correlate with increases in ball release speed (Pyne et al., 2006; Wormgoor et al., 2010), more recently Callaghan et al. (2021) did not find any relationship between physical capacities and pace bowling performance. This suggests further research is needed to investigate the transfer of physical improvements into an increase in bowling speed.

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 3) and were higher than international FB'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 3). 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 3). This significant increase in

ES 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 (Behringer et al., 2011). The current studies 14-week periodised programme, which was progressively overloaded seems to be consistent with the findings by Berhringer et al. 2011. These results support the coaches' perception that upper body strength and muscular endurance are important physical qualities to the developing fast bowler (theme 3, sub-theme 1), with one coach (coach 2) stating that bowlers who are not strong may be able to bowl fast but will breakdown in a couple of weeks if they are not strong enough.

Previously, positive correlations between ball release speed and maximum upper body strength (r = 0.74) have been shown in junior and senior populations (Pyne et al., 2006). During bowling the FB 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 (Stuelcken et al., 2007). Therefore, it could be suggested that FB's 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 (Stone et al., 2003; Suchomel et al., 2018) 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 fast bowler increase their BRS. The requirement of upper-body strength as an important physical quality to the FB's was stated by coaches within this and with previous literature on coaches' perceptions of fast bowling (Phillips et al., 2010, 2014) .

Whilst the coaches provided some agreement between the training programme results and the coaches' perceptions, additional themes actively emerged from the thematic analysis (part 1) that are pertinent to the aims of the current study, which may offer user generalisability due to the unique and in-depth experiences provided by each participant. For example, coaches (four out of six) identified several psychological traits, namely, bowler ego, aggression whilst bowling and motivation (theme 8, sub-theme 2) as being important to the developing fast bowler. Additionally, five of six stated player mentality and drive (theme 5, sub-theme 1 & 2) as being criteria used to identify developing fast bowlers. The findings are in agreement with previous studies (Phillips et al., 2010, 2014) who identified similar psychological traits with a lack of motivation and/or drive as being a reason experts cited for talented fast bowlers not progressing to elite level. This suggests developing fast bowlers would benefit from additional psychological support to assist them in developing these key psychological traits throughout their developing years and beyond.

Another interesting finding that emerged was the provision and implementation of physical preparation (theme 4, sub-theme 1). Six out of six coaches stated they implement physical preparation within their skills with four of six using the warm-up for improving fast bowlers' mobility, rotational power, and bowling technique. This is an effective and time efficient method for implementing physical preparation for teams with or without strength and conditioning coach assigned to their team. Furthermore, six out of six coaches (theme 11, sub-theme 1) stated strength and conditioning plays a vital role in the development of a developing fast bowler in terms of ensuring they have the physical qualities that underpin fast bowling that should in theory assist in optimising performance and increasing player longevity.

Finally, the author does recognise some limitations within the current study. First the sample size of developing fast bowlers was small; however, this was not only unavoidable due to the number of developing fast bowlers available for selection. This sample constituted approximately 30% of the total population who fitted the 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. Future research should consider the benefits of mixed methods research, where biomechanical, technical & physical provision are closely aligned within developmental programmes.

Practical Applications

This study set out to identify the technical, physical, and psychological characteristics required for successful performance in an adolescent FB and at the same time to develop and test an appropriate training model for adolescent and or developing fast bowling performance in cricket. The results from Part 1 of the study suggest that strength, power, cardiovascular endurance, and speed are physical characteristics that are required for a developing FB. In general, the coaches within the current study demonstrated an understanding of the global physical characteristics, such as strength, power, and cardiovascular endurance, that are required for successful fast bowling performance. However, coaches could benefit from understanding physiological and neuromuscular mechanisms that underpin these physical characteristics as this would help when discussing player physical development within the multi-disciplinary team. This is of particular importance when working with adolescent FB's. With the increasing need for athleticism in modern day cricket and most game-changing situations involving a combination of strength, power, muscular endurance, aerobic capacity, and speed, it is vital that FB's are in the best physical condition for the start of the season and can maintain this throughout the course of the year. Importantly, this study found that through physical preparation developing FB's can be nearly as physically capable as adults which has the potential to make them more robust and resistant to injury which links with 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 FB's should be the primary aim of strength and conditioning coaches (Kiely, 2020; Mukandi et al., 2014; Webster et al., 2020; Weldon et al., 2021). This will allow adolescent FB's to develop the required physical qualities that, in theory, should enhance playing performance and reduce the risk of injuries during their developing years.

As seen in appendix F, a well-rounded physical preparation programme can increase several important physical qualities such as strength, power, muscular endurance, speed, and aerobic capacity. Strengthening programmes that increase maximal neuromuscular strength in the lower-body are beneficial, with exercises such as squats, hip-hinge movements and lunging exercises forming the foundation of a FB's strength programme (Kiely, 2020; Mukandi et al., 2014). Additionally, increasing eccentric strength in the lower body can assist with maintain an extended knee during front foot contact which may increase delivery speeds. This can be achieved by programming exercises that target the eccentric component of the movement such as drop jumps (bilateral & unilateral), lowering phase of a squat (bilateral & unilateral), lowering phase of a leg extension/leg press (bilateral & unilateral). Furthermore, upper-body explosive strength and been shown to correlate with ball speed and thus power exercises such as bench throws and or tri-planar medicine ball variations targeting the upper-body may assist in increasing ball speed (Kiely, 2020; Pyne et al., 2006). Interestingly, this was not the case in the current study, this may be due to the complex nature of the associated sequencing of movements with fast bowling (Callaghan et al., 2021), an increased period, along with combined technical coaching, biomechanical and strength training may be required to transfer strength gains to improvements in ball speed.

As well as the physical qualities above, the conditioning component of the physical preparation programme should aim to develop the three energy systems (phosphagen, glycolytic and aerobic) to match the movement demands of the sport to ensure the FB can repeat and recover throughout the period of play (Petersen et al., 2010). This can be achieved through testing players aerobic and anaerobic abilities. The method used in the current study (Yo-Yo level 1) allows strength and conditioning coaches to match individualised test distances to match distance covered data.

Given the physical nature of fast bowling and the physiological differences amongst developing FB’s, strength and conditioning coaches should work closely with skills coaches to ensure evidence-based support is provided during this crucial stage of development. Introducing the use of biomechanical analysis earlier in the adolescent fast bowling coaching process could provide skills and strength and conditioning coaches with quantitative data (e.g., front foot-contact GRFs) that could be of use when individualising players training programmes, leading to additional improvements in performance. For example, analysing and correcting technique, for example running technique to increase run-up speed, maintain run-up momentum and body alignment through back and front foot contact (Kiely, 2020; King et al., 2016; Portus et al., 2004). This can be achieved by taking a multi-disciplinary approach which could feed into coach education and developmental programmes.

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Appendix

Appendix A

School of Life Sciences Research Ethics and Governance Committee

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 Masters in Research programme I am undertaking a research project. The title of my research study is:

"An investigation into the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowlers."

This study will explore, not only what technical, physical, and psychological skills required to be a successful adolescent fast bowler, but to focus on the optimal support mechanisms that surround and drive this process.

In order to take part in this study you must be qualified to the highest level within your retrospective countries, for example, Level 4 in the United Kingdom and South Africa and Level 3 in Australia and New Zealand. You must also have been involved in coaching cricket for at least 5 years and be part of the high-performance programme.

Should you fit the criteria, and prior to the start of the study, you will be required to complete an informed consent sheet. If you agree to participate in the study, to take part in a scripted online interview hosted on Microsoft Teams.

All data will be anonymised where possible and your name will be changed to a participant number. The data will be stored on a password secure electronic device and will only be made available to the researcher, supervisors and identified coaches. You have the right to withdraw from the study at any time before the anonymising of the data, once the data has been anonymised you will no longer be able to withdraw as your data will not be recognisable.

The data will be kept until the end of the study then will be destroyed in accordance with Edinburgh Napier University's data storage regulations.

The findings from this study will be used to inform current cricket fast bowling coaching practices used to assist in the development of adolescent developing FB.

If you require any further information and or have any questions please feel free to contact me (Scott Hislen). Any questions relating to the project I cannot answer will be referred to my supervisor Director of Studies Dr Cedric English, Dr Brendon Ferrier and Mykolas Kavaliauskas.

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.

[redacted]

Appendix B

Edinburgh Napier University Research Consent Form

An investigation into the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowler.

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 research study.

2. I understand that the purpose of this study is to identify the technical, physical, and psychological characteristics required for successful performance in an adolescent fast bowler.

3. I understand that my name will not be used for any other purposes than for this study and the researcher, project supervisors, and the Cricket Scotland youth performance coaching staff will be the only parties to view the data gathered from the qualitative study.

4. I also understand that if at any time during the study I feel unable or unwilling to continue, I am free to be removed without prejudice and all data collected will be destroyed in accordance with Edinburgh University's data storage regulations.

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 requirements for the study and all questions have been answered to my satisfaction.

7. I understand that all the data pertaining to the study will be stored on an encrypted mobile storage device and once completed all data pertaining to the study will be destroyed in accordance with Edinburgh Napier University's data storage regulations

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.

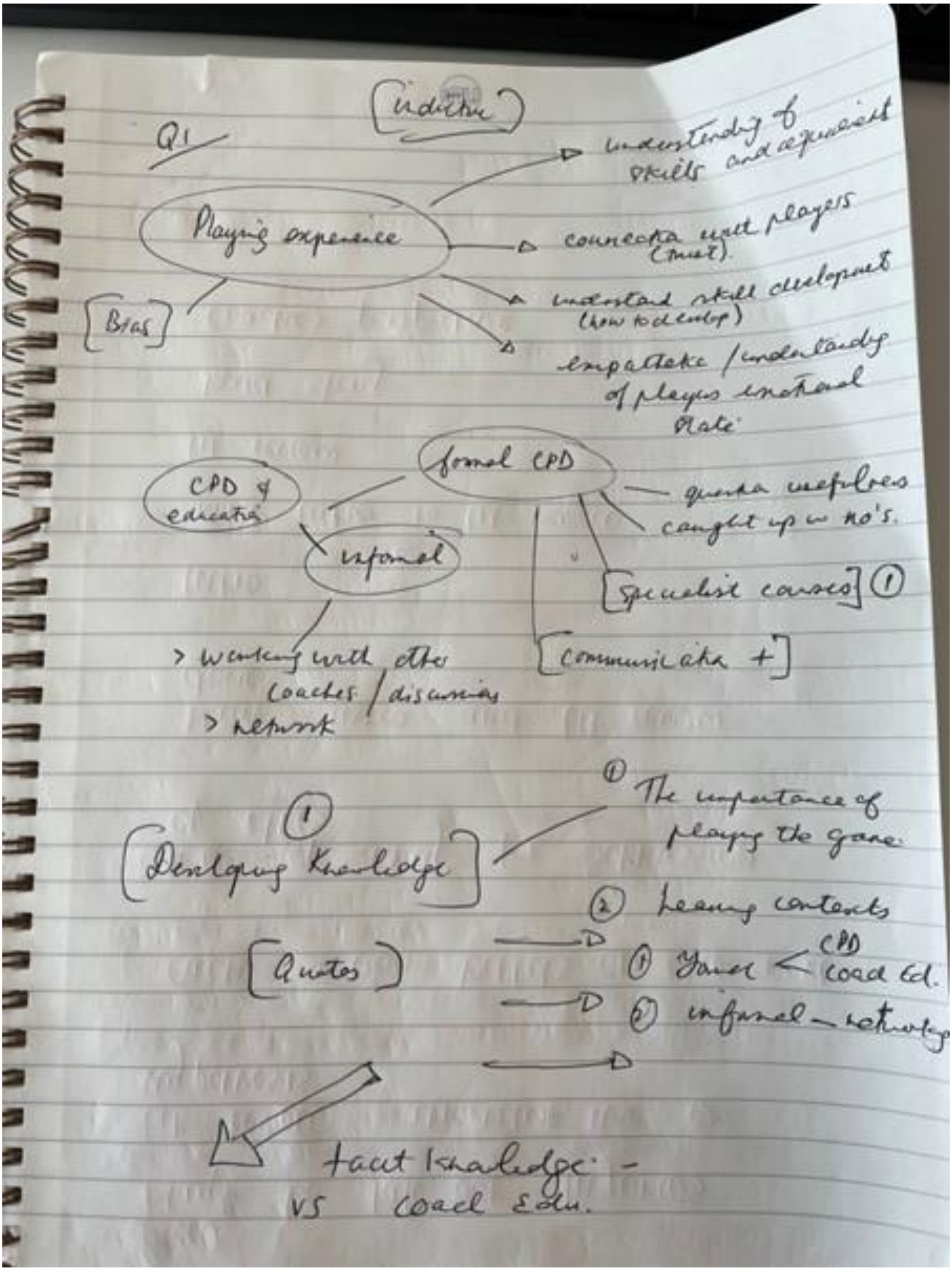
Participant's Signature Date

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.

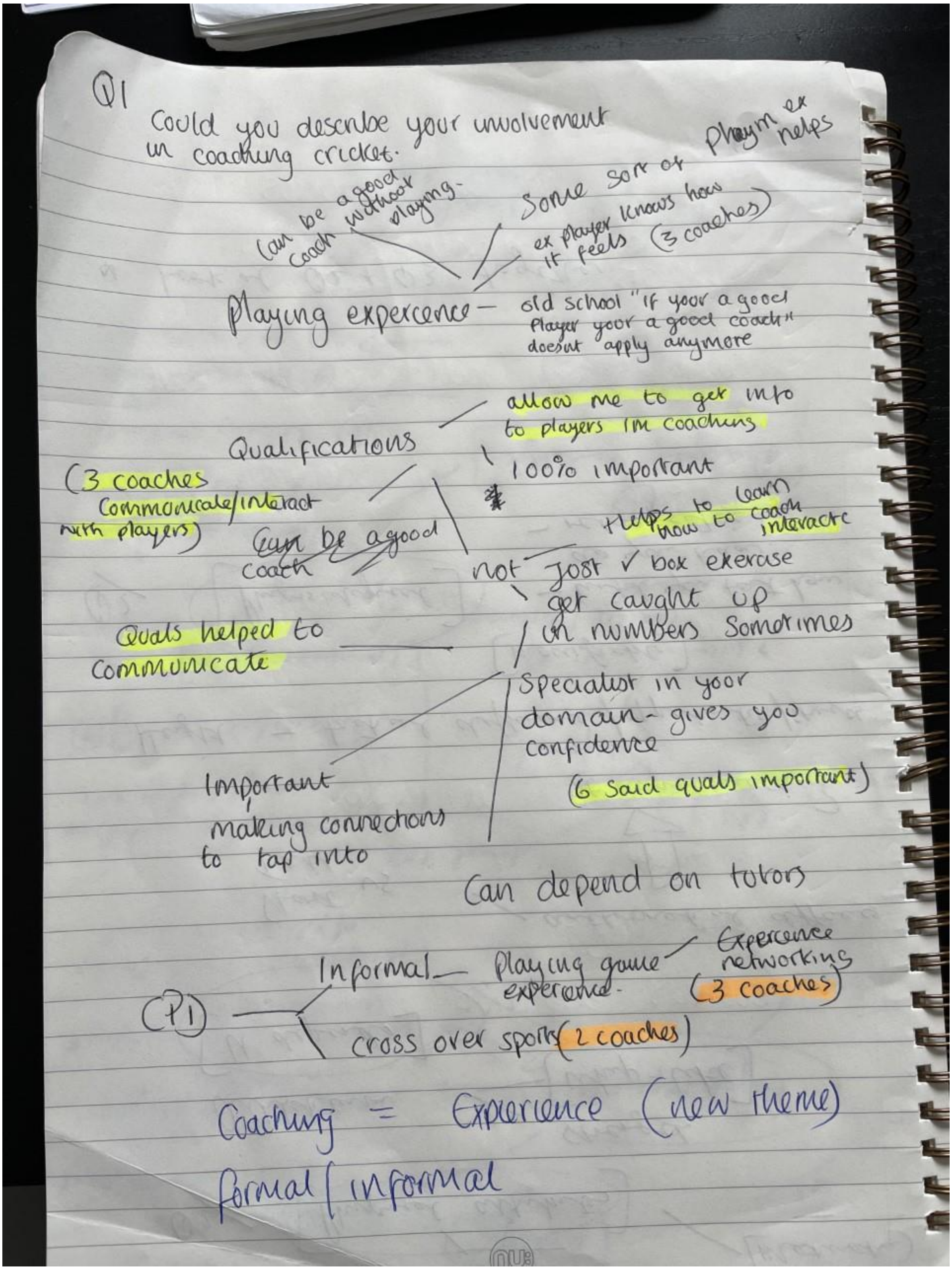
Researcher's Signature Date

Appendix C

Critical friend example



Researcher example



Appendix D

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.

In order 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 [redacted]. Any questions relating to the project I cannot answer will be referred to my supervisor Director of Studies Dr Cedric English [redacted]

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.

Edinburgh Napier UNIVERSITY

Appendix E

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 F

[redacted]

Appendix G

	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

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 H

	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	✓	✓	✓	✓	✓	✓	✓	✓