

Biomechanics, physiology, injury and conditioning for cricket fast bowlers

Bryan Stronach

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Signed



Bryan Stronach

Date 08/10/2014

CO-AUTHORED WORKS

The following four manuscripts have been accepted or are in preparation for submission for peer reviewed journal publication as a result of the work presented in this thesis.

Stronach, B., Cronin, J., Portus, M. Part. (2014). Part 1: Biomechanics, injury surveillance and predictors of injury for cricket fast bowlers. *Strength and conditioning journal*. 36, (4), 65-72

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The student was the primary contributor (90%) of the research in this thesis and the subsequent analysis and interpretation of the research results. The student was also the main contributor (90%) to the writing of research ethics applications, progress reports and papers, as well as being the main presenter of the research results at conferences. All co-authors have approved the inclusion of the joint work in this thesis.

Masters Candidate: Bryan Stronach



Primary Supervisor: John B Cronin



Secondary Supervisor: Marc Portus



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NOTE TO READER

Excluding chapter one, this thesis is presented as a series of chapters in publication submission format, which in some instances, due to the chosen submission format, there may be some repetition. Furthermore there may be a difference in writing style between the chapters so as to make them appropriate for the specific targeted journals. This thesis fulfils the AUT University Master of Sport and Exercise guidelines by conducting an applied research investigation in a relevant area. These pieces of research critique previous literature relevant to the topic and provide experimental application to the growing body of knowledge.

ABSTRACT

There are many different skills that are required for the sport of cricket but the most physically demanding and injury prone of these skills (Petersen, Pyne, Dawson, Kellett, & Portus, 2011; Petersen, Pyne, Dawson, & Portus, 2009; Petersen, Pyne, Portus, & Dawson, 2011) is fast bowling (Dennis, Farhart, Goumas, & Orchard, 2003; Mansingh, Harper, Headley, King-Mowatt, & Mansingh, 2006; Orchard, James, & Portus, 2006; J. Orchard, James, Alcott, Carter, & Farhart, 2002). The conditioning of cricket fast bowlers has received very little scientific attention. Therefore the purpose of this thesis was: 1) to conduct a thorough literature review that collated the findings of the limited research that has been undertaken and identified gaps in knowledge around best practice of strength and conditioning for fast bowlers that require further attention; 2) find the experts opinion on these identified areas of future research; and, 3) use the knowledge gained from both the literature and experts opinion to construct a suggested best practice strength and conditioning program for fast bowlers.

Using the Delphi method, a series of surveys were administered to a total of 61 fast bowling experts, who included strength and conditioning coaches, physiotherapist's, skills coaches and players, all of whom were specialists in the area of fast bowling and had five plus years' experience at first class or international level cricket. Questions were aimed at gaining consensus of opinion as to: 1) the specific field based tests that are best used to assess and monitor the specific fitness qualities of the cricket fast bowler; 2) the fitness qualities most important for the time of the season and developmental stage of the fast bowler; and, 3) best practice for maintenance of these fitness qualities through an in-season.

The main findings of these surveys were that strength and aerobic fitness rated the most important conditioning aspect for fast bowlers, with strength also rating as most important regardless of the development level of the bowler and the time of the season. A significant percentage of the experts believe that all conditioning areas can be maintained and potentially improved during the in-season of a busy international or domestic cricket season. This can mostly be achieved via performing one high intensity session every 10 days. Furthermore the experts suggested that all these qualities, with the exception of strength, can be trained/maintained via the demands of playing the game.

With regards to the strength demands. Different areas of the fast bowlers body require different focuses. Specific bowlers and body types require different training focuses. Some hypertrophy in the lower body is acceptable when it helps with injury prevention but extra non-functional mass (fat mass or extra muscle mass) in the upper-body is undesirable.

Another outcome of the survey was the identification of best practice assessment batteries for anthropometry, flexibility, strength, speed, power, anaerobic and aerobic fitness. Specific fast bowling tests were identified that were thought essential to complete the physical player profile. This included a movement screening test where the top five movements that need to be assessed and were specific to fast bowlers were the single leg squat, sprinting, squat, a shoulder mobility test and rotational movements.

CHAPTER 1: INTRODUCTION

Cricket is a major international sport with millions of dollars being spent and earned on the international and domestic scenes. It is a unique sport as it has three different formats that are played at the highest level. Multi-day cricket can be played over two-four days (domestic level) or five days at international level with both teams normally involved in two innings of batting and bowling/fielding. One day formats include the ODI's and T20 or 20/20 cricket. ODIs are played at all levels and involve one innings of batting and bowling/fielding for each team and can last for 40-50 overs (6 deliveries) and around 6 hours. Finally T20 or 20/20 cricket which is the shortest format involves one innings for each side of 20 overs and lasts around 3 hours. In all three formats players bat, bowl and field, therefore there are many different skills that are required for the game but the most physically demanding of these skills (Petersen, Pyne, Dawson, et al., 2011; Petersen, Pyne, Dawson, et al., 2009; Petersen, Pyne, Portus, et al., 2011) plus the skill that incurs the highest injury rate is fast bowling (Dennis et al., 2003; Mansingh et al., 2006; Orchard et al., 2006; J. Orchard et al., 2002).

Very little peer reviewed research and expert commentary has addressed best practice for conditioning of fast bowlers. What is known is that a fast bowler needs to be strong and lean in order to withstand and reduce the substantial forces (mean peak vertical forces between 3.8-12 times body weight, mean peak horizontal forces of 2-4.9 times body weight) that they have to endure during bowling (Elliott & Foster, 1984; Elliott, Foster, & Gray, 1986; Elliott, Hardcastle, Burnett, & Foster, 1992; Foster, John, Elliott, Ackland, & Fitch, 1989; Hurrion, Dyson, & Hale, 2000; Mason, Weissensteiner, & Spence, 1989). They also need to be an endurance athlete. This is due to the distances (average of 22.6km in multi-day, 13.4km in ODI's and 5.5km in T20 cricket) they cover in the different formats of the game (Petersen, Portus, & Dawson, 2009; Petersen, Pyne, Dawson, et al., 2011; Petersen, Pyne, Dawson, Portus, & Kellett, 2010; Petersen, Pyne, Portus, Karppinen, & Dawson, 2009). Finally they need to be a power athlete due to the explosive nature of the bowling action and given the published benefits of increased run-up speeds resulting in increased bowling velocity (Duffield, Carney, & Karppinen, 2009; Elliott & Foster, 1984; Glazier, Paradisis, & Cooper, 2000; Salter, Sinclair, & Portus, 2007). However,

there is a paucity of literature addressing how these qualities are developed and maintained in the cricket fast bowler.

As intimated there is some literature that has investigated the biomechanics, physiology and injury predictors of fast bowling, however the relevance, implications and transference of this knowledge to strength and conditioning practice is unexplored. Furthermore there is no doubt that the quality of the strength and conditioning program is affected by the diagnostic value of the assessments used to identify the strength and weaknesses of the fast bowler. Once again there is very little published research addressing assessment screens/profiles and how they guide programming for the fast bowler. Finally, researchers have not addressed how assessment and programming may differ for the developmental as compared to the senior fast bowler and how the fitness qualities of importance can be trained and maintained in season.

Purpose statement

The purpose of this thesis is to: 1) bring all the current peer reviewed research around strength and conditioning best practice for fast bowlers into a literature review and discuss the implications of these findings while identifying areas of identified future research; 2) determine the experts opinion on these identified areas of future research; and, 3) use the knowledge gained from both the literature and experts opinion to construct a suggested best practice strength and conditioning program for fast bowlers.

Significance of the research

The role that the physical condition of fast bowlers plays in terms of performance and injury prevention has been of concern for strength and conditioning coaches, physiotherapists, sports doctors, coaches, commentators, journalists and administrators. Little scientific attention has been undertaken in the area and therefore the implementation of conditioning programmes with a focus on performance and injury prevention can only rely on task analysis, educated opinion and best practice from other sports. Therefore there is a need to develop a guideline for evidence based best practice that is focused specifically on the needs of a fast

bowler. This thesis aims to accomplish this by integrating peer-reviewed research with expert opinion to formulate a best practice strength and conditioning program for fast bowlers. The findings should provide guidelines (assessment and prescription) for the developmental to experienced fast bowler as well as information specific to time of season conditioning practice.

Limitations

- The results from this research are generalised to the population of experts that choose to take part or were able to be surveyed.
- As experts are not held accountable during this research method, the motivation to complete the surveys in a comprehensive and/or meaningful manner may be problematic. However, given that the survey was voluntary, this limitation would be mitigated to some degree.
- This research methodology was restricted to experts who had access to the internet.
- The final chapter presents much needed recommendations for fast bowlers in an area that is sorely lacking evidence-based guidelines. Therefore, the guidelines provided should be seen as an important step in promoting evidence-based practice for fast bowlers but also viewed as preliminary in nature.

Delimitations

- To the best of the ability of the researcher this study was anonymous and thus bias from participants or the researcher was minimised.
- Although anonymous the online survey site used did report what country the participants responded from. This research had a large percentage of respondents from New Zealand, Australia, South Africa and England, therefore accounting well for western perception but has limited representation for the Asian perception of the needs of fast bowlers.

Framework of the thesis

This thesis will present itself as four separate chapters, written as individual studies prepared for journal submission. Chapter 2 reviews the literature on the biomechanics, injury surveillance and predictors of injury to fast bowlers. This review incorporates a discussion of the implications that the literature from these areas has for individuals involved in the strength and conditioning for cricket fast bowlers. Chapter 3 reviews the literature on mechanical and anthropometric factors of fast bowling for cricket, and implications for strength and conditioning. Chapter 4 outlines the results of an in-depth series of surveys that were undertaken via experts in the field of fast bowling in order to gain better insight into best practice of strength and conditioning for fast bowlers. Finally Chapter 5 collates the information from the literature reviews and combines this with the results gained via the surveys to produce a suggested strength and conditioning program that covers developmental to developed players and off-season through to in-season training progressions.

CHAPTER 2: BIOMECHANICS, INJURY SURVEILLANCE AND PREDICTORS OF INJURY FOR CRICKET FAST BOWLERS

Introduction

The role that the physical condition of fast bowlers plays in terms of performance and injury prevention has been of concern for strength and conditioning coaches, physiotherapists, sports doctors, coaches, commentators, journalists and administrators. Little scientific attention has been undertaken in the area and therefore the implementation of conditioning programmes with a focus on performance and injury prevention can only rely on task analysis, educated opinion and best practice from other sports. With this in mind, the following article reviews literature to help inform best practice regarding the conditioning needs of the cricket fast bowler (Portus, Sinclair, Burke, Moore, & Farhart, 2000). In this article the biomechanics of the bowling action, injury surveillance data, predictors of injury and the implications of these topics on strength and conditioning practice are discussed.

Search strategy

The studies under consideration for this review were drawn from peer-reviewed journal publications, conference proceedings or books. Varying combinations of the keywords 'strength and conditioning', 'biomechanics', 'time motion analysis/GPS', 'injury', 'predictors', 'ball release speed', 'testing', 'periodization' with the terms 'cricket' or 'fast bowlers' were used to filter relevant research from electronic databases such as Google Scholar, ScienceDirect, PubMed and SportsDiscus. Significantly, more hits were found (over 100 hits) through the Google Scholar searches as opposed to the electronic databases (1-30 hits), but the electronic database hits were far more specific to the search topic. Reference list referral was an equally important search strategy. Studies were included in the review if the investigation utilized any strength and conditioning or injury prevention procedure that was utilised for fast bowling within cricket.

Biomechanics of bowling action

Bowling in cricket involves a run-up and the circumduction of a straight arm about the glenohumeral joint to propel a 155.9–163.0 gram leather ball at a batter, who stands some distance away (approximately 17–18m or 22 yards) (Ferdinands & Kersting, 2007). This action of bowling can be divided into two distinct phases: the run-up and delivery stride which includes pre-delivery stride (Elliott & Foster, 1984).

Run-up

Run-up speed has become a major focal point for cricket coaches given the strong ($r = 0.58$) to very strong ($r = 0.74$) relationship of run-up velocity and ball release speed (Feros, Young, O'Brian, & Bradshaw, 2012). For example, Duffield et al. (2009) found a strong ($r = 0.52$) to very strong ($r = 0.70$) positive relationship between the faster that a bowlers velocity is during the final 5-metres of their run-up and ball speed. The faster the bowlers velocity in the final 5-metres of the run-up the faster the ball speed. The findings of Salter et al. (2007) also supported the importance of run-up speed, these researchers reporting that run-up velocity was an important determinant of ball release speed in a single bowler case study. Elliot and Foster (1984) considered that run-up speed should be sufficient to produce a high linear velocity while allowing the correct delivery technique to be adopted. To support this, Glazier et al. (2000) concluded that bowling actions that permitted faster horizontal velocity in the final stride were associated with faster ball speeds (Glazier et al., 2000). A higher linear velocity in the run up is desirable if: 1) that momentum can be transferred through the delivery stride and body to the ball; 2) it doesn't put the bowler at undue risk of injury due to excessively higher impact forces caused by an increased run-up velocity; and, 3) the bowler's delivery stride biomechanics are not adversely effected (Elliott et al., 1986; Portus et al., 2000; Salter et al., 2007). Noting these three provisions it may be concluded that improving running mechanics could help to improve a bowler's performance and bowling speed (Salter et al., 2007).

Researchers have shown that the stride prior to delivery (pre-delivery stride) for front on bowlers, is longer than a normal stride. This is caused by the apparent necessity to decelerate in the final stride and is probably associated with greater braking forces and the need to 'gather' for the final thrust (Bartlett, Stockill, Elliott, & Burnett, 1996).

Strength and conditioning implications for the “run-up”.

The fact that run-up speed and specifically the speed in the final 5-metres of the run-up has been shown to affect ball speed, means that strength and conditioning coaches can directly influence the ball velocity of a fast bowler. If appropriate for an individual bowler, strength and conditioning coaches can work with coaches to improve running technique, power and speed to firstly increase the maximum running speed of the bowler and then to transfer that running speed into their run-up. This enables some direction as where to start and what goals to concentrate on early in the fast bowler's development. The younger the age of an athlete, the more favorable it is for the development of the movement patterns needed for sport (Ljach & Witkowski, 2010). This means the younger and earlier that coaches and strength and conditioning coaches can start making changes to an athlete's running technique, the more chance they have in improving the athlete's maximum speed, and subsequent ball delivery speed.

While running speed and speed development is important for every athlete, it should be noted that it is very important for strength and conditioning coaches to work with bowling coaches and other specialists when changing a bowler's run-up speed. Many factors should be considered before altering run-up speed, such as: 1) if the athlete has developed enough strength to handle the increased ground reaction forces that they will incur if the final 5-metre running speed is increased; 2) whether the extra speed will affect bowling technique/accuracy; and, 3) if the extra ball speed will be a benefit or a hindrance to the bowler's performance. Furthermore, final run-up speed only accounts for 30-50% (Duffield et al., 2009) of ball speed variance so it is important to understand that there are other factors that influence the speed.

Deceleration from running requires large amounts of eccentric strength through the legs (Twist, 2005) and is often something that is overlooked by many strength and conditioning coaches. This coupled with plyometric bilateral (double leg) and unilateral (single leg) training needs to be undertaken in all specific bowling strength programs. This will help to prepare the bowler for the stresses associated with the pre-delivery stride by conditioning them to large eccentric forces and single leg nature of this pre-delivery stride.

Delivery stride

There are four bowling techniques or actions that have been used to classify the bowling actions of fast bowlers during the delivery stride (the final stride before ball release). They are the mixed, side-on, semi-open or front-on action (Ferdinands, Kersting, Marshall, & Stuelcken, 2010; Foster et al., 1989; Portus, Mason, Elliott, Pfitzner, & Done, 2004). These actions have been explained and expanded further by Portus et al. (2006) as the following (Elliott, Davis, Khangure, Hardcastle, & Foster, 1993; Portus et al., 2000):

Side-on: a shoulder segment angle less than 210° at back foot contact, a hip-shoulder separation angle less than 30° at back foot contact and shoulder counter-rotation less than 30° (Fig. 1a).

Semi-open: a shoulder segment angle from 210 to 240° at back foot contact, a hip-shoulder separation angle less than 30° at back foot contact and shoulder counter-rotation less than 30° (Fig. 1b).

Front-on: a shoulder segment angle greater than 240° at back foot contact, a hip-shoulder separation angle less than 30° at back foot contact and shoulder counter-rotation less than 30° (Fig. 1c).

Mixed: a hip-shoulder separation angle equal to or greater than 30° at back foot contact, or shoulder counter-rotation equal to or greater than 30° (Fig. 2).

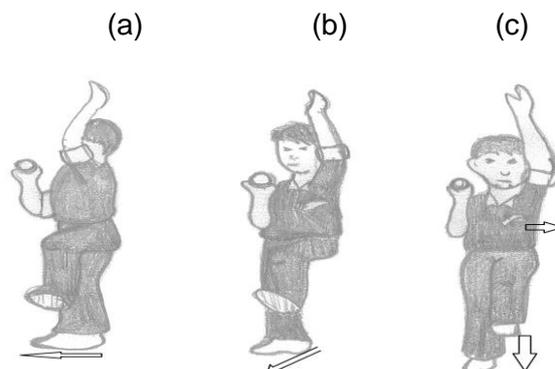


Figure 1. Front on view of the back foot set-up position of the (a) side-on bowling technique (b) semi-open bowling technique (c) front-on bowling technique.

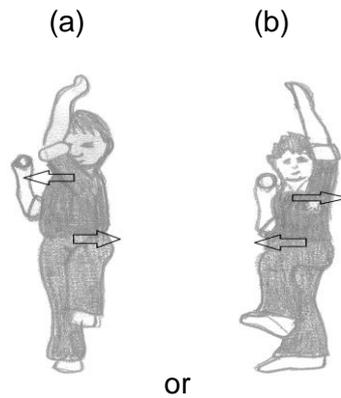


Figure 2. Front on view of the back foot set-up position of the mixed bowling action. (a) Shoulders in a more side-on position, (b) Shoulders in a more front-on position.

The mixed action bowler has a more laterally flexed and hyper-extended trunk at front-foot impact and a body position further from the upright orientation at ball release (Burnett, Barrett, Marshall, Elliott, & Day, 1998).

A great deal of research has investigated bowling biomechanics and injury (Burnett et al., 1996; Elliott et al., 1993; Elliott & Foster, 1984; Foster et al., 1989; Hides, Stanton, McMahon, Sims, & Richardson, 2008). One of the strongest relationships reported is between the classification of the different bowling techniques and lower back injury, specifically, the relationship between the mixed bowling action and lower back injuries (Bartlett, 2003; Bartlett et al., 1996; Elliott et al., 1993; Portus, Mason, et al., 2004; Salter et al., 2007). Portus (2004) reported that shoulder counter rotation (excessive amounts being a feature of the mixed bowling action), was significantly higher in a group of bowlers that incurred a stress fracture when compared to a no trunk injury group (Portus, Mason, et al., 2004).

In the legal delivery of a fast ball, large ground reaction forces are produced firstly by the back foot contact with the ground and secondly by the front foot contact with the ground (Hurrion et al., 2000). Several studies that have assessed the ground reaction forces of front foot contact. They have reported a range of mean peak vertical forces between 3.8-12 times body weight, with mean peak braking forces between 1.4 and 4.5 times body weight (Elliott et al., 1993; Elliott & Foster, 1984; Elliott et al., 1986; Elliott et al., 1992; Foster et al., 1989; Hurrion et al., 2000; Mason et al., 1989; Portus, Mason, et al., 2004). Furthermore mean peak horizontal forces on the back foot were in the range 2.0-4.9 times body weight, with mean peak braking forces

between 1.0-1.1 times body weight (Elliott et al., 1992; Portus, Mason, et al., 2004). Bartlett et al. (1996) suggested that a large initial peak ground reaction force during front foot contact, together with lateral flexion, hyperextension and rotation of the lower back, could be a major cause of lower back injuries.

Front foot contact has attracted research interest due to the relationship between knee angle and ball release speed. If the front knee is extended during the delivery stride it acts as a rigid lever and has a positive influence on ball release speed. If it flexes then it acts as a shock absorber and has a negative effect on ball release speed (Glazier et al., 2000). A straight leg technique with a front knee angle of greater than 150 degrees is thought to be the most advantageous to generating higher ball release velocities (Bartlett et al., 1996; Elliott et al., 1986). A technique that flexes and extends during the front foot phase has also been recommended (Worthington, King, & Ranson, 2010). Although a straight leg technique can produce greater ball release speeds it is also a potential injury risk. When the front leg is more flexed the muscle structure absorbs the energy or pressure that is being transferred. While that energy is lost in terms of performance it does mean that the bowler's ankles, knees, hips, back etc does not endure the same load (Crewe, Campbell, Elliott, & Alderson, 2013; Portus, Mason, et al., 2004)

Strength and conditioning implications for the “delivery stride”.

The relationship between the mixed bowling action and lower back injuries means strength and conditioning coaches need to become aware of the bowling actions of their fast bowlers. Although there should be a focus on core conditioning for all fast bowlers as their trunk must flex, extend, laterally flex and rotate, it would seem logical to have a major concentration on strengthening and therefore supporting the lower back region of the bowlers who use the mixed action. This also brings to attention the lack of specific research on strength and conditioning with regards to specific bowling actions. It is understood that the mixed action bowling group is more prone to injury and specifically lower back injury. This group of athletes requires specific conditioning that is different compared to what is needed for other bowling actions. Rotational training where the muscle structures responsible for creating rotation are strengthened and conditioned specifically is something that could help with this. Rotation and counter-rotation is an action that occurs throughout all the bowling actions yet there is a lack of understanding and knowledge as to how strength and conditioning can use rotational training to help performance and reduce injury. It would seem logical that rotational conditioning is part of a fast bowler's conditioning

program. However it needs to be understood to what level these areas need to be conditioned, what specific exercises help reduce injury and increase performance.

The large ground reaction forces that the fast bowler deals with through the delivery stride are undoubtedly a major contributor to the high injury rates. To withstand these forces a large amount of leg strength and specifically eccentric leg strength is needed to help with the absorption of those forces. Future investigations are needed to direct us towards the strength requirements/thresholds that are needed to align with the specific ground reaction forces of a bowler. For example, for bowlers that represent 9 body weights of vertical ground reaction forces at delivery, can a strength value be aligned with this? If the bowlers can achieve this value does this reduce the likelihood of injury? Secondly, what other specific physical attributes are needed by the athlete to withstand these ground reaction forces?

Being aware of the angle of the knee at front foot contact of the delivery stride also has implications to the programming of a bowler's resistance program. The leg needs to be eccentrically strong so that the bowler's body can decelerate quickly (Karppinen, 2010b), thus allowing an increased transmission of forces from the legs through the core and upper body for ball release. Although no research has found a significant relationship, it would seem logical that reactive strength of the leg is also an important consideration for the fast bowler's resistance program. During the front foot impact the front knee needs to eccentrically flex and then concentrically extend before ball release (Feros et al., 2012). Further research needs to be undertaken to assess first, the relationship between reactive strength and ball speed and second, the trainability of the bowlers in this area so that performance can be improved

Injury statistics

Orchard et al. (2002) have examined injury statistics concluding that One-Day internationals have an average injury prevalence (average number of squad members not available for selection through injury for each match, divided by the total number of squad members) of 10%. Injury prevalence was higher in pace bowlers (14%) than spin bowlers (4%), batsmen (4%), and wicket keepers (2%). They reported that the major risk factors for injury were: the speed at which the bowler delivers the ball; bowlers who had bowled a high number of match overs in the week before a match (more than 20); if the bowler had a large number of days of

play leading up to a match; and, bowling second (batting first) in a match (J. Orchard et al., 2002). Orchard et al. (2006) as a continuation from their original 2002 paper, found that fast bowlers miss, through injury, about 16% of all potential playing time compared to all other playing positions that miss less than 5% (Orchard et al., 2006).

A study by Mansingh et al. (2006) investigated the injuries of West Indian cricketers through the 2003-2004 seasons. They found that most injuries were sustained in Test matches, and that first class (four day cricket) and Test matches (five day cricket) led to 40% of all injuries. Of the remainder, 32% were in One-Day matches and the left over 28% occurred in training. T20 cricket was not mentioned (Mansingh et al., 2006).

Orchard et al. (2008) reviewed injury statistics over a 10-year period, until the 2007-2008 season. Injury incidence (the number of injuries occurring per match or per season) remained at a fairly constant level over the 10 year survey period. Injury prevalence (the percentage of players missing through injury in a given point in time) has gradually increased over the 10 year period in line with increases in scheduling (J. Orchard, James, Kountouris, & Portus, 2008). This does not necessarily mean injuries have increased. This could mean athletes are missing more playing time, due to a compressed schedule, for the same amount of time any given injury requires for rehabilitation and return to sport. Therefore as the schedule increases so too does the injury prevalence. With this in mind, Orchard and colleagues discussed the implications that the advent of T20 cricket had on injury incidence and prevalence of fast bowlers. They suggested that if there was no reduction in first class cricket and hence the schedule simply becomes more full due to extra matches, there would be a statistical increase in injury rates. However, if there was a reduction in other forms of cricket to allow more T20 cricket to be played then the injury rates of fast bowlers would be reduced. This is due to the current injury occurrence in T20 being lower than other formats (J. Orchard et al., 2008). This is due to the reduced workload of the bowlers in this form of the game (Dennis et al., 2003; Foster et al., 1989; Hides et al., 2008; Orchard et al., 2006; J. Orchard et al., 2008; J. Orchard, James, Portus, Kountouris, & Dennis, 2009).

Finch et al. (2009) reported that the incidence of bowling injuries increases with age in cricketers from the under-9 to under-16 level (Crewe, Elliott, Couanis, Campbell, & Alderson, 2012; Finch, White, Dennis, Twomey, & Hayen, 2009). These findings were supported by Shaw and Finch (2007) who also stated that injury frequency

significantly increased up to the age of 16 (Shaw & Finch, 2007). Research from Stretch (2003) and supporting research (Finch et al., 2009; Shaw & Finch, 2007; Stretch, 1993, 1995) showed that the younger players (up to 24 years) sustained more overuse (59.3%) and bowling (56.9%) injuries than the older players. All 14 of the stress fractures sustained in the research occurred to the younger players, with 13 of these injuries attributed to bowling. This research suggests that injuries appear to be frequent until athletes reach the age of around 24 years (Crewe et al., 2012; Finch et al., 2009; Shaw & Finch, 2007; Stretch, 1993, 1995).

A large percentage of bowling injuries involved the back (26.3%) or the lower limbs (14%) (Stretch, 1995). This is supported by research that showed 22.8-50% of injuries occurred in the lower limbs (Leary & White, 2000; J. Orchard et al., 2002; Stretch, 1993, 2001) and 18-33% of the total amount of injuries in the trunk (Leary & White, 2000; Stretch, 1993, 1995, 2001). Stretch (1995) reported that 56.1% of the total recovery time taken to return to sport was taken up by these two injury sites.

Stretch (2001) investigated the time of season when fast bowlers sustained these injuries. They reported that 45.3% of all the total bowling injuries occurred during the pre or early part of the season (Stretch, 2001).

Strength and conditioning implications for “injury prevention and rehabilitation”.

The fact that a large percentage of injuries for fast bowlers are occurring during the pre or early part of the season provides some insight and therefore direction to strength and conditioning programs. 1) Either the program that has been undertaken has not developed the bowler's fitness to the desired level of conditioning and therefore the bowlers are getting injured. 2) the program is not getting them to the intensity level required and the jump in intensity from training to games is too much, or their bowling workload is increased too rapidly, irrespective of their strength and conditioning program and their body has not had the time for the required adaptation to withstand this extra bowling.

Likewise some conclusions could be drawn from the fact that most injuries to fast bowlers occur in Test or 1st class cricket. This would again suggest that the extra load of the increased distance covered and higher bowling loads associated with the longer form of the game has caused a high prevalence of injury, due to the athlete

not being conditioned to a level where they can handle that load. Obviously more appropriate conditioning and careful scrutiny of bowling workloads needs to occur.

The implication of the introduction of T20 cricket to the international and domestic schedules has yet to be fully understood. Future research is needed to address the issue of adding in an extra format of cricket reduces what was already a very small window of non-competition training time that fast bowlers only sometimes get. Or the other formats (1day, test/4day cricket) be reduced to allow the inclusion of T20 cricket without affecting the non-competition training time. If the off or pre-season is reduced then there needs to be a far greater emphasis on getting bowlers to the high levels of condition that are required by fast bowlers before they start their domestic or international careers, or only partly introducing these athletes into the playing programme and creating the time needed to carry on their physical development. This demand for highly conditioned bowlers at earlier stages of their careers has created the increasing importance that international teams are placing around academies at a state/county/provincial level. This then means that the strength and conditioning during a player's adult career can mainly be based around maintenance rather than trying to improve conditioning levels while involved in a busy schedule.

Injury prevalence has slowly increased over the last 10 years along with the increase in scheduling (J. Orchard et al., 2008), suggesting that strength and conditioning programs have not catered for the extra load that is placed on the bowlers through simply playing and training more. A major question that arises from this is do we need to simply improve the level of condition of these bowlers or is it more of a periodising issue where athletes, strength and conditioning coaches and skills coaches need to introduce a periodised program that give specific periods for rest, recovery, adaptation and conditioning.

Predictors of injury

Although there has been limited international injury surveillance data, researchers have suggested that medium-fast and fast bowlers are the players at greatest risk of injury in cricket (Dennis, Finch, McIntosh, & Elliott, 2008; Orchard et al., 2006; J. Orchard et al., 2002). The major concern is the overuse injuries sustained by bowlers. Bowling workload has been identified as a major predictor of bowling injury (Hides et al., 2008). Workload and its relationship to injury was formally studied in 1989, when Foster et al. (1989) stated that excessive bowling workload was related

to lower back injuries in teenage fast bowlers. The authors concluded that bowling too many overs in any single spell and/or bowling too many spells may lead to back injuries to the bowler (Foster et al., 1989). Where an acute phase of bowling workload significantly exceeds a players recent bowling workload there is an increased risk of injury (Dennis et al., 2003; Hulin et al., 2013; Orchard et al., 2006; J. Orchard et al., 2009).

Dennis et al. (2008) suggested that there were two distinct pathways of how these bowling overuse injuries occurred: 1) continuous excessive exposure to a pattern of loading caused tissue to weaken to the point of injury; or, 2) an otherwise normal load causes failure of the tissue that has already been weakened due to an existing injury (Dennis, Finch, McIntosh, et al., 2008). The research on bowling loads and injury is slowly expanding. A study by Dennis et al. (2003) of ninety fast or medium fast bowlers found that: 1) those bowlers with an average of fewer than 2 days, or 5 or more days between bowling sessions were at a significantly increased risk of injury; 2) players who on average bowled fewer than 40 deliveries per session may be at an increased risk of injury as compared with those bowlers who on average bowled more than 40 deliveries per session; and, 3) bowlers with an average of fewer than 123 deliveries per week or more than 188 deliveries per week may be at an increased risk of injury (Dennis et al., 2003). This was supported by Dennis et al. (2004) who also found that those bowlers who bowled in five or more sessions in any 7-day period may have been at 4.5 times the risk of sustaining injury.

A significant increase in deliveries per session was observed in the 8-21 days prior to the date of injury for the injured bowlers as compared with the average number of deliveries per session in the 8-21 days prior to the uninjured bowlers. Dennis et al. (2004) suggested that recent periods of high bowling workload, including bowling more than 5 sessions in a week or more than 520 match deliveries in a month, had a highly significant role in the occurrence of injury, which suggests that a sudden escalation in bowling workload should be avoided, especially if this increased workload is sustained (Dennis, Farhart, Clements, & Ledwidge, 2004). Some game specific areas of risk and therefore predictors of injury are: 1) there is a greater risk of injury in the second innings of first class matches (compared to the first innings); 2) a greater risk of injury in the second game of back-to-back matches; and, 3) an increased risk of injury in the rare situation of enforcing the follow-on in a test match (Orchard et al., 2006). These areas of risk can all be related to workload as they are all factors that increase the amount or frequency of bowling.

Orchard et al. (2009) found that the injury incidence after a high workload was at its worst between 14 and 28 days after the workload (peaking 21-28 days) and not in the 1-13 days directly preceding the high workload. Therefore the penalty for an acute high workload may not be fully realized immediately after the load, but may occur up to a month after the acute increase in bowling workload. The reason for this was hypothesized that the damage occurring during bowling requires replacement of the damaged weaker tissue and then the repair of that tissue (J. Orchard et al., 2009). This means that mature (old) tissue continues to function for short periods after the overload without loss of function. However, after a period when the natural process of tissue turnover has resulted in the breakdown of some of the mature (old) tissue, the tissue that was previously damaged breaks away and it takes time for tissue to be replaced adequately. It is during this time of turnover that injury susceptibility is increased (J. Orchard et al., 2009). Interestingly a study by Hulin et al (2013) found that the greater the increase in acute workload (i.e. fatigue) compared to chronic workload (i.e. fitness) the larger the injury risk is for the following week (Hulin et al., 2013). This has major implications for strength and conditioning coaches and is discussed in the below section.

It is important to note that not only bowling workload but technique and physical characteristics of fast bowlers may place them in a higher injury risk category. It has been found that fast bowlers who used the mixed action recorded the highest amount of lower back injuries. This is due to the excessive counter-rotation during the bowlers delivery stride (Bartlett, 2003; Bartlett et al., 1996; Burnett et al., 1998; Elliott et al., 1993; Ferdinands, Kersting, et al., 2010; Glazier et al., 2000; Portus, Mason, et al., 2004; Ranson, Burnett, King, Patel, & O'Sullivan, 2008). Other risk factors such as injury history, posture, anthropometric characteristics, footwear and playing surfaces have also been linked to injury for fast bowler's (Dennis et al., 2003). Dennis et al. (2008) also found that out of 35 measures tested only two were identified as independent predictors of injury. Reduced hip internal rotation on the back foot impact leg was associated with a significantly decreased risk of injury, and reduced ankle dorsiflexion on the front foot impact leg was associated with a significantly increased risk of injury (Dennis, Finch, Elliottc, & Farhart, 2008).

Strength and conditioning implications for “predictors of injury”.

A significant amount of research has shown that an excessive bowling workload or spike in bowling workload is a major predictor of injury to fast bowlers. Strength and

conditioning coaches, bowling coaches, the athletes themselves and any others involved in the athlete's program, need to collaborate and plan a progressive workload program to manage risk factors to a suitable level of load and intensity that as close as possible replicates the demands of competition, while avoiding a spike or jump in load that might cause injury. The ideal time period for this process is yet to be determined and should be the subject of further research. This loading program also needs to be factored into the wider conditioning plan. If a bowler is in a rest or lighter period of bowling but in a high intensity phase with their physical conditioning, then the rest and adaptation may not be significant enough to prevent injury.

The finding of injury incidence being at its worst between 14 and 28 days after a spike in bowling loads has very simple but significant implications and can be used as a guideline as to when the fast bowler needs to be in a rest or lighter phase of bowling after a spike in loads. During the 14-28 days it is important to consider that this as a light phase of training rather than an off or high phase. If the athlete carries on bowling and training at a high load and intensity then the tissue will be at its weakest and therefore very susceptible to injury. If this time is considered an off period and no training or bowling takes place then the athlete runs the risk of being deconditioned and susceptible to injury upon return or taking longer periods of time to return to the game than expected.

The findings of Hulin et al (2013) are very significant for strength and conditioning coaches (Hulin et al., 2013). As stated the physical demands of cricket have only recently come to light. There is still a large history of cricket being perceived as the sport that you did not have to be physically conditioned for. As a result we still have athletes who physically under prepare. This research highlights that if a fast bowler is under prepared the chances of injury are significantly higher the week after a spike in bowling loads than the bowlers who are physically prepared, regardless of the Orchard et al (2009) findings.

Summary

The sport of cricket is unique in the fact that it has three different formats in which the workload and intensities of the athlete's vary greatly. The physical preparation for players needs to address many fitness components and the transition between formats needs to be planned very carefully as quite often player's transition between the three formats of the game is undertaken in short periods of time (or in 1 competitive series or similar).

Injury prevalence was higher in pace bowlers than any other position in cricket. The major risk indicators for injury were: bowling action, the speed at which the bowler bowls; bowlers who had bowled a high number of match overs in the week before a match; if the bowler had a large number of days of play leading up to a match; and, bowling second (batting first) in a match. Multi-day cricket sustained the highest percentage of injuries of all the formats. Injury prevalence has gradually increased in line with increases in scheduling of games. The suggested outcome of how the growing trend of T20 cricket will affect the injury rates of fast bowlers will depend on how T20 affects the schedule. If there is no reduction in multi-day and one-day cricket and hence the schedule simply becomes more cluttered, there is no doubt there will be an increase in injury rates if player rotation policies are not implemented. However, if there is a reduction in other forms of cricket to allow more T20 cricket to be played, then the injury rates of fast bowlers will be reduced as they do not get injured as much in T20 cricket. Careful consideration to bowling workload plans, especially early in the season, needs to be a focus of coaching staff.

When measuring vertical ground reaction forces through the front foot of fast bowlers, mean peak forces between 3.8-12 times body weight were reported, with braking mean peak forces between 1.4 and 2.5 times body weight. In some instances higher ball release speeds have been linked to longer upper and lower limb lengths, faster approach speeds and a straighter front leg at delivery. In particular the run-up of a fast bowler and how fast they are moving in the last 5 metres of their run-up has been shown to affect the speed of delivery. Given this information, it would seem that increasing the run-up velocity of the fast bowler could be a desirable adaptation, provided other aspects for the bowling action and performance outcomes are not compromised. There also needs to be a concomitant increase in the strength of the

trunk and leg musculature to absorb the probable increase peak vertical and horizontal ground reaction forces.

The specific bowling technique of a fast bowler is normally of concern to skill coaches but as there is a relationship between the mixed bowling action and lower back injuries, strength and conditioning coaches need to be aware of the specific bowling action that the bowlers they are working with. These actions and the way they place stress on the body will significantly influence the amount and type of conditioning work that is under taken with those bowlers.

CHAPTER 3: MECHANICAL AND ANTHROPOMETRIC FACTORS OF FAST BOWLING FOR CRICKET, AND IMPLICATIONS FOR STRENGTH AND CONDITIONING

Introduction

The role that the physical condition of fast bowlers plays in terms of performance and injury prevention has been of concern for strength and conditioning coaches, physiotherapists, sports doctors, coaches, commentators, journalists and administrators. One issue that confronts all is that physical preparation programs are for the most part based on conjecture, opinion or educated guesses (Portus et al., 2000). Little scientific attention has been undertaken in the area and therefore the implementation of conditioning programmes with a focus on performance and injury prevention can only rely on task analysis, educated opinion and best practice from other sports. With this in mind the following article reviews literature to help inform best practice regarding the conditioning needs of the cricket fast bowler. In this article the mechanical and anthropometric factors thought to be important determinants of fast bowling are examined, time motion analysis that provides better insight into the physiological demands of the cricket fast bowler are detailed and the implications for strength and conditioning practice are discussed.

Search strategy

The studies under consideration for this review were drawn from peer-reviewed journal publications, conference proceedings or books. Varying combinations of the keywords 'strength and conditioning', 'biomechanics', 'time motion analysis/GPS', 'injury', 'predictors', 'ball release speed', 'testing', 'periodization' with the terms 'cricket' or 'fast bowlers' were used to filter relevant research from electronic databases such as Google Scholar, ScienceDirect, PubMed and SportsDiscus. Significantly more hits were found (over 100 hits) through the Google Scholar searches as opposed to the electronic databases (1-30 hits), but the electronic database hits were far more specific to the search topic. Reference list referral was an equally important search strategy. Studies were included in the review if the investigation utilized any strength and conditioning or injury prevention procedure that was utilised for fast bowling within cricket.

Predictors of ball speed

A major attribute to performance is the speed at which a fast bowler can deliver the ball. As stated previously, the faster the release speed the less reaction time the batter has and the more difficult it is for the batter to play the ball (Elliott et al., 1986). There is only limited information on the characteristics related to fast bowling ball speed. Pyne et al. (2006) found that the static jump, bench throw, counter movement jump, and body mass all correlated positively ($r=0.86$) to increased ball velocity. For senior bowlers, the best set of predictor variables were deltoid throw, static jump, counter movement jump, arm length, and anterior-posterior chest depth ($r=.074$) (Noakes & Durandt, 2000).

Velocity based factors

Run-up velocity has been attributed as an important determinant of ball release speed (Ferdinands & Kersting, 2007; Ferdinands, Marshall, & Kersting, 2010; Salter et al., 2007). Glazier et al. (2000) reported a strong relationship ($r = 0.70 - 0.731$) between the horizontal velocity of the run-up during the pre-delivery stride and ball release speed (Glazier et al., 2000). Although this relationship exists it was also shown by Glazier et al. (2000) that in front-on bowlers the run-up only accounted for 16.2% of ball release velocity. The rest was acquired from hip action 1.6%, trunk action 5.7%, hand and finger action 14.3% and arm action 62.2% (Glazier et al., 2000). Ferdinands et al. (2010) noted that side-on bowlers with a shoulder alignments of less than 20° may not be as reliant on run-up velocity as bowlers with more open shoulder alignment (Ferdinands, Marshall, et al., 2010). It would seem that front-on bowlers require more momentum from their run-ups to have a similar ball release speed as side-on bowlers (Elliott & Foster, 1984; Ferdinands, Marshall, et al., 2010).

Run-up speed was also investigated by Duffield et al. (2009) where they reported a moderate to strong correlation ($r = 0.70$) between the speed that a bowler was able to maintain through the final 5 metres of their run-up and peak/mean ball speed. The run-up was examined further to find that fast bowlers (as opposed to medium fast bowlers) achieved a final 5 metre run-up speed that was $89\% \pm 6\%$ of peak 30 metre sprint velocity (Duffield et al., 2009).

Although run-up velocity measured as centre of mass velocity at back foot contact (run-up velocity at back foot contact in the delivery stride) was also shown to have a correlation to ball release speed by Ferdinands et al. (2010), it was found that it was not the only predictor of ball release speed. They suggested that although a basic level of run-up velocity was necessary to bowl fast, other kinematic factors were still needed to explain the variance in ball speed between faster bowlers. This was found when they studied the negative acceleration of the centre of mass over the delivery stride. Simply put, the deceleration of the centre of mass of a bowler during their delivery stride accounted for 43.1% of total ball speed. They stated that it was apparent that the deceleration of the bowler was more important than the velocity acquired by the bowler (through their run-up). In general, the centre of mass deceleration was the most important kinematic factor associated with ball speed. This was particularly evident within the faster bowling group where the bowlers achieving the fastest ball speeds displayed greater deceleration (Ferdinands, Marshall, et al., 2010; Wormgoor, Harden, & Mckinon, 2010). A key to this deceleration is the front knee angle during the delivery stride which has been discussed in the biomechanics section on this paper (Bartlett et al., 1996; Elliott et al., 1986; Loram et al., 2005; Portus, Rosemond, & Rath, 2004; Portus et al., 2000; Wormgoor et al., 2010). A straight leg technique with a front knee angle of greater than 150 degrees is thought to be most advantageous in generating greater ball release velocity (Bartlett et al., 1996; Elliott et al., 1986). Feros (2012) suggested that in order for the fast bowler to take full advantage of the forces and momentum that were being produced by the legs, there needs to be an effective transfer of that momentum through the core and upper body. Core stability rather than abdominal strength was seen as being the key and therefore a significant indicator of ball velocity (Feros et al., 2012).

Loram et al. (2005) also found that the angle at which peak torque occurred for internal and external shoulder rotation on an isokinetic dynamometer had a slight relationship ($r = 0.21$) to ball release speed when it was part of a regression model that incorporated knee angle during delivery. This was supported by Wormgoor et al. (2010) who stated that increased strength of the bowlers arm's extensor muscles resulted in higher ball release speeds for certain bowlers. In essence there is a slight relationship between shoulder strength and ball release speed that cannot be ignored but the amount of strength remains undefined (Wormgoor et al., 2010).

Wormgoor et al. (2000) found a relationship ($r^2 = 0.15$) between concentric shoulder extension strength and ball release speed that was unique to their research. Supporting other research they also found that greater front leg knee extension at ball release (Bartlett et al., 1996; Elliott et al., 1986; Loram et al., 2005; Portus, Rosemond, et al., 2004; Portus et

al., 2000; Wormgoor et al., 2010), shoulder alignment in the transverse plane rotated further away from the batsman (smaller shoulder alignment angle) at front foot strike (Portus, Mason, et al., 2004) and greater ankle height during the delivery stride (Bartlett et al., 1996) were all connected to higher ball release speeds (Wormgoor et al., 2010). Wormgoor et al. (2000) showed a moderate relationship ($r = -0.47$) between being more side-on at front-foot contact and ball release speed. It is important to note that this is not counter-rotation, but counter-rotation can lead to this position. Although this can be seen as an advantage for a bowler through enabling them to get into this position, a side-on bowler with minimal counter-rotation can also achieve this position, which is the safer and equally effective method to generate ball speed (Portus, Mason, et al., 2004).

Anthropometry

Bowlers of larger physical stature and greater strength generally have a higher ball velocity (Pyne, Duthie, Saunders, Petersen, & Protus, 2006). Glazier et al. (2000) hypothesized that an ectomorphic physique such as those that are apparent in the fast bowlers of Afro-Caribbean origin is optimal for high ball release velocity (Glazier et al., 2000). This physique included a greater percentage of type II muscle fibers (Ama et al., 1990). Noakes et al. (2000) also suggested that superior genetic endowment may be more important than physical training in determining who is going to be able to achieve greatest ball release velocities (Noakes & Durandt, 2000). Portus et al. (2000) stated that a bowler with a larger and leaner upper torso bowled faster than those with a smaller and less lean upper torso (Portus et al., 2000). A larger and leaner overall body composition was also related to bowling faster, but not as highly related as upper torso. In agreement to this was Stuelcken et al. (2007) who found that male fast bowlers possessed a large anterior – posterior chest depth, calf girths and arm girths. Other physical characteristics of the body that have a strong correlation to ball release velocity are shoulder-to-wrist length and total arm length (Glazier et al., 2000; Pyne et al., 2006; Stockill & Bartlett, 1994). Loram et al. (2005) and Wormgoor et al. (2010) however, reported that in their study, longer limb lengths did not contribute to higher ball release speeds. While they recognized that the mechanical advantage of longer limbs must in theory benefit some bowlers, based on their results it was concluded that such factors are only of minor importance (Loram et al., 2005; Wormgoor et al., 2010).

Strength and conditioning implications for “predictors of ball speed”.

From a strength and conditioning perspective, the faster the bowler is moving in the run-up and the bigger the deceleration, the faster the ball release speed. These findings enable a specific focus to training, however, it is important to be aware of the implications increased approach velocity and deceleration have. For example, if the run-up speed is increased and the front knee angle during the delivery stride is high, then this in turn will increase the already high ground reaction forces that fast bowlers have to endure. This means for the bowler to achieve this performance outcome the strength and conditioning coaches need to develop a whole program around making sure that the athlete has developed enough physical ability to handle the extra load.

The correlation between a bowler's leaner anthropometry, ball speed and lower injury rates is an important aspect to consider. Not only do leaner athletes have an advantage when it comes to performance outcomes such as running speed (Kreider et al., 1998) and ball release speed, but athletes being leaner has substantial implications for injury prevention. Theoretically, given the exact same bowling action, the vertical GRF of a lighter bowler should be less since force is the product of mass and acceleration. Following this logic it would be beneficial for the fast bowler to be as lean as practical to reduce the GRFs they have to endure during an over, innings and game. This can be achieved through reduction of fat or through the reduction of unwanted muscle mass. For example, increasing muscle mass in the upper body will increase the vertical GRF but may not give any functional performance benefit to a fast bowler. Careful consideration needs to be given to functional mass changes and the anthropometric blueprint for the fast bowler.

Physiological requirements

Cricket is unique in that there are three different game formats, namely T20, One Day, and multiple-day (Test and first-class) cricket, in which the physiological demands vary greatly (Petersen, Pyne, Dawson, et al., 2011; Petersen, Pyne, Dawson, et al., 2009; Petersen et al., 2010; Petersen, Pyne, Portus, et al., 2011; Petersen, Pyne, Portus, et al., 2009). The following discussion focuses on the time motion analysis literature associated with these different formats as related to fast or medium-fast bowlers.

Petersen et al. (2009, 2010, 2011) have provided the most extensive research into the time motion analysis of cricket and fast bowling. The research investigated the variability in movement patterns during one day internationals by a cricket fast bowler (Petersen, Pyne, 37

Portus, et al., 2009) and quantified their positional movement patterns in T20 cricket (Petersen, Pyne, Dawson, et al., 2009). It was stated that International fast bowlers undertook the greatest amount of work of any cricketing position analysed in the one day format, as shown in: Table 1 - the average total distances covered walking (10,914 m), jogging (2,490 m), running (560 m), striding (798 m) and sprinting (1,140 m); and, Table 2 - the average number of sprints (66), average sprint distance (18 m), maximum sprint distance (54 m) and, maximum sprint speed (8.3 m/s) (Petersen, Pyne, Portus, et al., 2009). Second it was stated that fast bowlers and fielders cover substantially greater distance than spin bowlers and wicket keepers in T20 cricket. The fast bowlers covered a total distance of 8.5 ± 1.5 km, sprinted 42 ± 8 times, an average sprint distance of 17 ± 2 m for a total sprinting distance of 0.7 ± 0.2 km (Petersen, Pyne, Dawson, et al., 2009).

Petersen et al. (2010) provided some general statistics on bowling compared to fielders and batsmen. Of all the positions, fast bowlers operated with the greatest intensity across all formats of the game. Compared with other positions, fast bowlers covered 20–80% greater distance, covered 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 at least 35% less recovery time between high-intensity efforts. Additionally, an analysis of repeated sprint activity (defined as a minimum of three sprints with mean recovery duration between sprints of less than 60 s) found that only fast bowlers undertook sprinting in clusters (Petersen et al., 2010). Furthermore, Petersen, Pyne et al. (2009) found that international fast bowlers undertook the greatest amount of work of any cricketing position analyzed. The bowler covered 16 km in 3.5 hours, which was almost twice the workload of cover-point fielders (in first-class cricket), who covered 15.5 km in 6 hours (Petersen, Pyne, Portus, et al., 2009).

Petersen et al. (2010) found that T20 cricket was 22% and 43% more intensive for fast bowlers than One Day and multi-day cricket respectively, in terms of the hourly sprint distance (Table 2). Yet, the cumulative sprinting in T20 and One Day games was only 39 and 80% of the daily (6 h) 1.4 km sprinted during multi-day cricket. During T20 cricket fast bowlers were required to run 340 and 400 metres greater distance per hour than One Day and multi-day cricket, respectively. Yet in absolute terms, fast bowlers on average covered a total distance of 22.6, 13.4, and 5.5 km in multi-day (6 h), One Day, and T20 innings respectively. Consequently, T20 and One Day cricket required only 24 and 59% of the total distance covered in multi-day cricket. It was also found that fast bowlers meet the repeated sprint activity definition of “an episode of three or more sprints (speed of >5.01 m.s) with less

than 60 seconds recovery between efforts”, 5-6 times during 1day and multi-day cricket (Petersen et al., 2010).

Table 1: Distance covered (metres/hour) by fast bowlers in various forms of the game (Peterson et al. 2010)

	Walking	Jogging	Running	Striding	Sprinting
T20	2634±261	718±276	164±76	249±121	406±230
One-Day	2520±362	618±217	157±58	220±81	316±121
Multi-day	2512±258	614±173	185±89	233±133	230±149

Table 2: Sprints by fast bowlers (Sprint = movement above 5 metres/sec for at least 1sec)

	Sprints/hour	Mean sprint distance (m)	Max sprint distance (m)	Number of sprints/hour	Recovery ratio (1:x)
T20	23±10	17±4	35±13	61±25	25±18
One-Day	18±5	18±3	46±12	54±14	25±7
Multi-day	17±11	13±1	28±5	56±29	38±31

Adapted from Peterson et al. (2010)

Peterson et al. (2011) have recently focused on the comparison of player movement patterns between One-Day and Test Cricket (Petersen, Pyne, Portus, et al., 2011) and the comparison of training and game demands of national level cricketers (Petersen, Pyne, Dawson, et al., 2011). The first of these comparisons found that cricketers generally covered similar distances in both formats but for fast bowlers in state-level cricket, the intensity of One-Day cricket was greater than the multiday cricket format. Future analysis should determine if this finding applies to international fast bowlers (Petersen, Pyne, Portus, et al., 2011). The second of these studies provided the first quantitative description of the movement demands of various types of training drills undertaken by elite cricketers. Fast bowlers had similar mean heart rates in T20 cricket as in simulation and skill drills but much lower than in conditioning drills. This was also true when it came to intensity levels where similar levels were reached between T20 cricket, simulation and skill drills but higher levels of intensity were reached in conditioning drills (Petersen, Pyne, Dawson, et al., 2011).

When interpreting these findings it must be remembered that players within the same team experience substantially different workloads, depending on the ground size, length of bowling spells or number of deliveries and their position, and role within a particular game. An example of this is a fast bowling all-rounder (bats up the batting order and bowls) as

opposed to a fast bowler (bats down the batting order and bowls). The bowling all-rounder has the opportunity to bat for a longer time period and therefore cover more distance than a bowler who does not have the same opportunities (Petersen, Pyne, Portus, et al., 2009).

Strength and conditioning implications for “physiological requirements”.

Time motion analysis has given the strength and conditioning coach a great insight into the physical demands of a cricket fast bowler's. Given the nature of the fast bowlers workload, it is important that the program trains all three energy systems (phosphagen, glycolytic & aerobic), rather than concentrating on one. Assessment of the individual athlete's natural ability will also inform the focus placed on each of these energy systems.

There has been a large emphasis placed on bowling loads in that there should be gradual increases in bowling loads, so that the body's tissues can adapt and strengthen. Although to a lesser degree the same is evident for total distance covered. If an athlete is only covering a small distance and at the wrong intensities in the lead up to a game or series and then goes and covers 16 kilometres in a one day game or 22 kilometres in a single day of a multi-day game and then repeats this many times over, then in many cases the increase in load is too high for the body's tissues to handle and injuries can occur. Strength and conditioning coaches need to be inventive with ways of progressively building the distances and intensities covered so that the body's tissue can adapt and strengthen so that when the bowlers cover the high distances and intensities that are required of them in games, the body's tissues is strong enough to withstand undue fatigue and injury.

The introduction of a shorter, more intensive cricket, in the form of T20, has had major implications to the fast bowler's strength and conditioning program. The increased amount of time spent in the higher intensity zones needs to be replicated in their conditioning program. The attractions of large amounts of money, the decreased injury risk associated with T20 cricket and a busy schedule has contributed to the growing trend towards bowlers specializing in either the shorter or longer forms of the game. These athletes mainly specialize in one of three ways with each group displaying unique and specific strength and conditioning needs: 1) bowlers who are playing all formats of cricket – their program needs to cover all energy systems and strength aspects evenly; 2) bowlers who are only playing the longer formats – the program needs to cover all energy and strength aspects but with a higher emphasis on conditioning for the longer lower intensity distances that they need to cover; and, 3) bowlers who only play the shorter formats – their program needs to have an added emphasis on the higher intensities and does not need to condition for the large

distances covered in the longer formats. The big benefit to the bowlers who end up specializing is they have far more non-competition time in which they can concentrate on conditioning.

Physical conditioning

The increasing professionalism of cricket and the demands on cricket players, places a much larger importance on conditioning for these players. A recent review of the literature on cricket concluded that much more research was required before a full understanding of the scientific aspects of the game could be made (Bartlett, 2003). The role of physical preparation and specifically muscle re-education has had little to no investigation (Hides et al., 2008).

General conditioning practice that applies to many sports and exercise activities are also applicable to cricket and should be followed by cricketers to try to improve performance and decrease the potential of injury. These areas of conditioning include cardiovascular/energetic, strength/power, flexibility, speed/agility and endurance (Patel, Stier, & Luckstead, 2002).

Johnstone and Ford (2010) gave some guidelines as to what strength and conditioning coaches should concentrate on according to the specific demands of cricket and the associated playing positions. They suggested that strength and conditioning coaches should, after completion of a general training program, focus on developing lower-body speed (explosive and repetitive) and anaerobic upper-body power within players. Greater flexibility in the lower lumbar and hamstrings could be needed within the bowling group because of the functional requirements during the delivery stride. It was found that athletes within the study who had engaged in a periodised program achieved superior performance ratings within the sprinting, upper-body power and flexibility assessments in comparison with their peers, thus providing further evidence to the cricket community about the value of a long-term annual periodized program (Johnstone & Ford, 2010).

The effect of strength training among injured fast bowlers and the affect that this had on multifidus was researched by Hides et al. (2008). The cross sectional area of the multifidus increased by 20.7-26.2% for those bowlers with low back pain who received the training programme compared to those who did not receive the training programme who increased by 4.6-4.8%. There was also a 50% reduction in the reported pain levels of the players with

lower back pain, thus suggesting that strength training can help with bowlers return to sport (Hides et al., 2008).

It has been suggested that a reason for the high fatigue levels of fast bowlers could be due to the damage that comes through repeated bouts of eccentric contractions, which have been shown to require substantial muscle strength to reduce the extent of this damage (Morgan & Allen, 1999; Thompson, Nicholas, & Williams, 1999). For this reason more attention needs to focus on the eccentric muscle strengthening of fast bowlers. In addition Naokes et al (2000) concluded with the fact that very high fitness levels are needed to meet the demands of cricket (Noakes & Durandt, 2000).

There is a high amount of repeated sprints or shuttles in the game of cricket (Noakes & Durandt, 2000; Petersen et al., 2010; C. Petersen, D. Pyne, B. Dawson, & M. Portus, 2009). All shuttles include acceleration and deceleration phases (Thompson et al., 1999). During a deceleration phase the greatest stress and therefore greatest fatigue is placed on the hamstrings. This is due to the work the hamstrings have to do eccentrically to slow flexion of the hip, extension of the knee, and during the landing phase of a stride (Thompson et al., 1999). Thompson et al. (1999) studied the effect of this type of activity in intermittent athletes with little or no long-term preparation. It was shown that there was a marked increase in muscle soreness and markers of muscle damage. Implicit from these findings is the need for long-term preparation in all sports that involve multiple sprints including fast bowlers.

Pyne et al. (2006) suggested that cricket training programs for younger fast bowlers (14.8 ± 1.3 years) should focus on skills and technique development, with older juniors making the transition to senior ranks requiring more specific strength and conditioning work (Pyne et al., 2006). The reason for this was the fact that strength gains became more apparent in the late teens and early twenties (Faigenbaum, 2000), therefore athletes would gain more performance benefits from technique gains (Pyne et al., 2006).

Karppinen (2010) suggested that traditional strength training to achieve neural adaption to maximize eccentric strength and contractile rate of force development through increasing mass is not as applicable to cricket as it is to other sports. This concept has been largely misunderstood when it is assumed that increasing mass is thought to be the sole means in which strength and power is improved. It is possible to design resistance training programs for fast bowlers where they achieve gains in muscle strength with minimal or no gains in muscle mass (Karppinen, 2010b). This is very important when understanding the ground reaction forces that the athlete's musculature has to absorb during a run-up phase where

they need to absorb between 3.8-12 times of their body weight of vertical and braking forces through the delivery of the bowling action (Phillips, Portus, Davids, Brown, & Renshaw, 2010). Karppinen (2010) also suggested that maximum strength development of the upper extremities may be pointless as the fast bowler does not have time to reach maximum force capability. This is due to the fact that on average, time to peak force for a fast bowler takes 0.4 of a second, whereas the relative contributions during the action of the upper extremities allow only about 0.15-0.18 of a second to be generated (Phillips et al, 2010). Ideally strength training programs for fast bowlers should include a focus on technique and achieving physical competency in the early formative years and move to more of injury prevention and performance improvement focus as training age increases (Karppinen, 2010b). In conclusion Karppinen (2010) stated that with the modern international schedule, strength training is necessary to maintain the required high level of intensity and high performance.

Table 3 is a needs analysis for fast bowling by Feros et al. (2012) that included exercises to develop physical capacities based on the current biomechanical, physiological and strength data presented in the literature they reviewed (Feros et al., 2012).

Table 3: Needs analysis for fast bowling (Feros et al., 2012)

Physical Capacity	Importance			Exercises
	Low	Mod	High	
Muscular Strength - Upper Body - Lower Body - Core		Y	Y	Bench Press / Bench Pull Squat / Deadlift / Lunge BB Standing Trunk Rotation
Muscular Power - Upper Body - Lower Body - Core			Y	Bench Press Throw / MB Chest Throw Power Cleans / Snatches / Jump Squats Overhead MB Throw / Lunge with MB Throw
Reactive Strength - Lower Body			Y	Single or Double Leg Depth Jump / Skipping
Speed - Acceleration - Endurance - Maximum		Y	Y	20m Sprint 20m Sprint, Repeated 40m Sprint
Anaerobic Capacity			Y	20m Sprint Repeated
Aerobic Capacity		Y		400m Sprint Repeated

Y = Yes, BB = barbell, MB = medicine ball, Mod = moderate

Table used with permission - Journal of Australian Strength and Conditioning (JASC)

Strength and conditioning implications for “physical conditioning”.

The major implication from the findings around the physical conditioning of fast bowlers is that for many aspects of strength and conditioning a “best guess” approach to bowler development is used. Fast bowlers require speed, power, strength, flexibility, anaerobic and aerobic fitness to a high level as well as good nutritional habits. Although there has been some great insight into fast bowlers’ conditioning, it is many of the specific needs for individual fast bowlers’ in terms of injury prevention and performance that are yet to be

researched e.g. It would seem that the conditioning requirements of a bowler would change when they have a slightly different bowling action.

Summary

Of the different disciplines involved in the game of cricket, fast bowlers undertake by far the greatest workload throughout all of these formats. The distance covered (metres/hour) by fast bowlers, when compared across formats was not significantly different at lower intensities, but as the game format shortened the difference in distance covered at higher intensities becomes significantly greater. The shorter the game the greater the distance covered at high intensity.

The assessment of fast bowlers at the basic level needs to cover all the aspects of conditioning that they encounter. Largely the assessment battery covers the general conditioning principles of strength, power, speed, aerobic, anaerobic as well as anthropometric and flexibility aspects. These are relatively simple field based tests that are used at not only at international level but all levels of sports. What is more difficult to understand is the specific physical requirements of fast bowling and the assessments that can guide strength and conditioning programming. This is an area that needs far more investigation in order for best practice to be adopted. If a specific conditioning area is found to have a positive relationship towards a bowler's injury prevention or performance then it needs to be monitored.

From the information presented it would seem that after completion of a general training program where bowlers have had a focus on strength (including power and eccentric training), aerobic conditioning, anthropometric and flexibility aspects, bowlers should focus on developing lower-body speed (explosive and repetitive) and anaerobic upper-body power. Greater flexibility around the lower lumbar and hamstrings could be needed within the bowling group because of the technical movements that occur during bowling delivery. Attention needs to be given to the ideal anthropometry of the fast bowler. Theoretically, given the exact same bowling action, the vertical GRF of a lighter bowler should be less since force is the product of mass and acceleration. Following this logic it would be beneficial for the fast bowler to be as lean as practical to reduce the GRFs they have to endure during an over, innings and game. This can be achieved through reduction of fat or through the reduction of unwanted muscle mass. For example, increasing muscle mass in the upper body will increase the vertical GRF but may not give any functional performance

benefit to a fast bowler. Careful consideration needs to be given to functional mass changes and the anthropometric blueprint for the fast bowler. Finally the bowling workloads of this cohort need to be managed judiciously.

CHAPTER 4: A SURVEY OF BEST PRACTICE STRENGTH AND CONDITIONING FOR CRICKET FAST BOWLERS.

Introduction

Cricket is a major international sport with millions of dollars being spent and earned on the international and domestic scenes. It is a unique sport as it has three different formats that are played at the highest level. Multi-day cricket can be played over two-four days (domestic level) or five days at international level with both teams normally involved in two innings of batting and bowling/fielding. One day formats include the ODI's and T20 cricket. ODIs are played at all levels and involves one innings of batting and bowling/fielding for each team and can last for 40-50 overs (6 deliveries) and around 6 hours. Finally T20 or 20/20 cricket which is the shortest format involves one innings for each side of 20 overs and lasts around 3 hours. In all three formats players bat, bowl and field, therefore there are many different skills that are required for the game but the most physically demanding of these skills and the focus of this paper is fast bowling (Petersen, Pyne, Dawson, et al., 2011; Petersen, Pyne, Portus, et al., 2011; Petersen, Pyne, Portus, et al., 2009).

Very little peer reviewed research and expert commentary has addressed best practice for conditioning of fast bowlers. What is known is that a fast bowler needs to be strong and lean in order to withstand and reduce the substantial forces (mean peak vertical forces between 3.8-12 times body weight, mean peak horizontal forces of 2-4.9 times body weight) that they have to endure during bowling (Elliott & Foster, 1984; Elliott et al., 1986; Elliott et al., 1992; Foster et al., 1989; Hurrion et al., 2000; Mason et al., 1989). They also need to be an endurance athlete. This is due to the distances (average of 22.6km in multi-day, 13.4km in ODI's and 5.5km in T20 cricket) they cover in the different formats of the game (Petersen, Portus, et al., 2009; Petersen, Pyne, Dawson, et al., 2011; Petersen et al., 2010; Petersen, Pyne, Portus, et al., 2009). Finally they need to be a power athlete due to the explosive nature of the bowling action and given the published benefits of increased run-up speeds resulting in increased bowling velocity (Duffield et al., 2009; Elliott & Foster, 1984; Glazier et al., 2000; Salter et al., 2007). However, there is a paucity of literature addressing how these qualities are developed and maintained in the cricket fast bowler.

As intimated there is some literature that has investigated the biomechanics, physiology and injury predictors of fast bowling, however the relevance, implications and transference of this

knowledge to strength and conditioning practice is unexplored. Furthermore there is no doubt that the quality of the strength and conditioning program is affected by the diagnostic value of the assessments used to identify the strength and weaknesses of the fast bowler. Once again there is very little published research addressing assessment screens/profiles and how they guide programming for the fast bowler. Finally, researchers have not addressed how assessment and programming may differ for the developmental as compared to the senior fast bowler and how the fitness qualities of importance can be trained and maintained in season. Given the gaps in the literature and the practical nature of the information sought, a survey of “experts” in this area was thought the best means to provide the knowledge necessary to guide best practice strength and conditioning for cricket fast bowlers. With this in mind the purpose of the survey was to: 1) identify the specific field based tests thought best to assess and monitor the specific fitness qualities of the cricket fast bowler; 2) detail the fitness qualities most important for the time of the season and developmental stage of the fast bowler; and, 3) describe best practice for maintenance of these fitness qualities through an in-season.

Methods

A series of surveys were used to determine if there was a consensus of opinion amongst “experts” with regards to the conditioning of fast bowlers in cricket. Survey 1 (Physical conditioning program for fast bowlers: the research and experts’ opinion) requested participants’ opinions about broad areas of a strength and conditioning program. Survey 2 (Physical conditioning program for fast bowlers: the research and experts’ opinion. This survey requested participants’ agreement or disagreement on many of the results derived from Survey 1, but also sought to extend and clarify those results.

A modified Delphi technique was used to design the surveys. The Delphi technique is a process using written responses for two or more surveys, in order to try and achieve a consensus (Becker & Roberts, 2009). The Delphi technique is popular in health services research (Becker & Roberts, 2009) and provides the opportunity to survey opinions of individuals who would be difficult to bring together physically due to geographic or financial constraints. In this study, participants were sent an email and asked if they would like to participate in the survey. If they agreed then they were directed to a web based link to access the survey.

Subjects

The fast bowling experts recruited for this study involved strength and conditioning, physiotherapy, skills coaches and players, all of whom were specialists in the area of fast bowling. These professionals were requested to participate based on their involvement and experience with elite fast bowlers. Pre-existing professional relationships between the authors and international cricket organisations in New Zealand, Australia, United Kingdom, India, Sri Lanka, Bangladesh, South Africa, Canada and Pakistan were used to recruit participants. To be included in the study the participants needed to have been involved in first class or international cricket for three or more years.

A total of 58 responses were recorded for the first survey with 23 (39.7%) of those responses being strength and conditioning coaches, 21 (36.2%) from specific skills coaches, 9 (15.5%) physiotherapist responses and 8 (13.8%) athlete responses. The response rate for Survey 2 was slightly lower with 51 responses. Twenty one (41.2%) of these were strength and conditioning coaches, 15 (29.4%) specific fast bowling coaches, 8 (15.7%) physiotherapist and 7 (13.7%) athlete responses.

Survey 1 consisted of 25 questions (2 open ended questions and 23 closed ended questions). Questions 1-5 focused on the framework of the screening tool and sub-grouping the participants into strength and conditioning coaches, physiotherapists, skills coaches and players. Questions 6-25 required participants to rate importance and give their thoughts on the different energy systems, strength and anthropometric qualities that they thought important to the different formats of cricket and the best ways to assess these components.

After the results from Survey 1 were collated and analysed, Survey 2 was created. As in accordance with the Delphi technique, the content of Survey 2 was based on the results or majority answers to Survey 1. The objective of Survey 2 was to expand on the answers to Survey 1 and gain extended information around the fitness qualities identified as important, including the differentiation between developmental and experienced players throughout a cricket season. Additionally, Survey 2 sought clarification on areas of confusion from the findings of Survey 1.

Data analysis

Many question types were used and therefore the data were derived in different ways. Rating scales were used where each participant could vote once in different categories which produced a percentage to each answer or gave a simple rating of 1-4 for important to least important answer. The answer with the lowest total score was considered the top ranked. Different ranking systems were also employed where a vote was given as to whether or not a category was important or not. A percentage was given depending on how many votes were received in that category out of the total respondents.

Statistical analysis

All respondents were grouped together for the benefit of the analysis. Percentage analyses for responses to all questions were conducted. Categorical and ordinal data were reported as both absolute numbers and percentage of responses. Scores for ranked questions were determined by weighted calculation in Surveygizmo.

Results/discussion:

Conditioning priorities

Table 4: Ratings of the fitness qualities thought important for cricket fast bowlers across three formats of the game.

	Aerobic		Anaerobic		Speed		Strength		Power		Anthropometry		Flexibility	
	Not Important / Semi Important	Important / Very Important	Not Important / Semi Important	Important / Very Important	Not Important / Semi Important	Important / Very Important	Not Important / Semi Important	Important / Very Important	Not Important / Semi Important	Important / Very Important	Not Important / Semi Important	Important / Very Important	Not Important / Semi Important	Important / Very Important
Test / Multi day	5.4%	94.6%	7.1%	92.8%	16.1%	83.9%	5.4%	94.7%	21.4%	78.6%	12.5%	87.5%	16.1%	83.9%
ODI's / 1days	7.2%	92.8%	3.6%	96.5%	14.3%	85.7%	5.4%	94.7%	23.2%	76.8%	16.1%	83.9%	16.1%	83.9%
Twenty20	17.8%	82.2%	7.1%	92.8%	12.5%	87.5%	7.2%	92.8%	21.4%	78.5%	19.7%	80.4%	14.3%	85.7%
Average		89.7		94.0				94.1%		78.0				

It can be observed from Table 4 that the respondents rated all conditioning areas for the most part as important to very important for fast bowlers across all formats of the game. The development of strength was rated the highest (94.1%) but very closely followed by anaerobic fitness (94.0%) whereas power the lowest (78.0%). The largest variation (12.4%) between the formats of the game was observed for aerobic fitness, where the respondents thought that aerobic fitness was less important to T20 cricket in comparison to the other longer formats.

Strength was the fitness quality rated as the most important quality for fast bowlers. This was attributed to the large ground reaction forces that the bowler has to endure during the delivery of the bowling action. During the bowling action peak vertical ground reaction forces range between 3.8 to 12 times body weight, with mean peak braking forces between 1.4 to 4.5 times body weight (Elliott et al., 1993; Elliott & Foster, 1984; Elliott et al., 1986; Elliott et al., 1992; Foster et al., 1989; Hurrion et al., 2000; Mason et al., 1989; Portus, Mason, et al., 2004). The

experts suggested that fast bowlers needed to be strong through the lower body to help withstand these forces. It was also suggested that strength was an essential component of power and that the bowling action is a power movement.

The reasons for anaerobic fitness being highlighted as one of the most important fitness qualities needed by fast bowlers across all formats of the game, were firstly due to the anaerobic nature of bowling (repeated sprints) and the specific distances that are covered during a game. In the first instance it was suggested that repeated speed ability was crucial as it is understood that repeatedly achieving near maximum sprints has a huge influence on the bowlers ability to perform (Duffield et al., 2009). In the second instance Peterson et al (2009, 2010, 2011) reported that up to 9 km can be covered at varying intensities by fast bowlers for Twenty20 matches, up to 16 km for ODI's/1dayers and in excess of 22 km per day can be covered during Test/Multi day games (Petersen, Portus, et al., 2009; Petersen, Pyne, Dawson, et al., 2011; Petersen et al., 2010). For athletes to cover these sorts of distances they need to have a strong aerobic base but many experts believed that this can be achieved via anaerobic type training (Adela, Mirela, & Mirela, 2013; Tabata et al., 1996; Tomlin & Wenger, 2001). This type of training helps the fast bowler train specifically for the repeated sprint nature of bowling and incorporates higher speed plus can involve high intensity accelerations and decelerations, which typical aerobic training does not always involve.

Respondents believed that power development was still very important for fast bowlers but the least important out of all the fitness qualities. It was stated that "If there is time, power development will become part of a strength and conditioning program, but if athletes are limited by time then this will be the first thing to go". Reasons for this were mainly due to the fact that it was believed that the athletes achieved a lot of power development from doing their core skill of bowling fast and that the strengthening of muscle for performance and injury prevention was more important. However it should be noted that this is a sub-optimal approach and if time allows a good concentration on power training should be adopted.

There was a large variation (12.2% between 20Twenty and Test/Multi, 10.6% between 20Twenty and ODI/1dayers) between the formats of the game in terms of the rating of aerobic fitness. The general consensus was that the bowlers did not cover as much distance and did not bowl as many overs in the shorter formats of the game and therefore aerobic fitness was less important. Not many bowlers are only involved in one format of the game (e.g. most 20Twenty bowlers still play ODI/1day cricket), so coaches need to keep this in mind when prioritising the training of various fitness qualities. Furthermore, researchers have shown that recovery is enhanced with greater aerobic fitness (Bell, Snydmiller, Davies, 52

& Quinney, 1997; Tomlin & Wenger, 2001), this no doubt of practical benefit given the short turn around between matches when on tour.

Table 5: Ranking of conditioning areas and their importance depending on time of season for developmental and experienced fast bowlers.

	Developmental Fast Bowler			Experienced Fast Bowler		
	Off-season	Pre-season	In-season	Off-season	Pre-season	In-season
Strength	1	1	1	1	1	1
Speed	3	3	2	3	3	2
Aerobic Fitness	2	4	4	2	4	4
Anaerobic Fitness	4	2	3	4	2	3

Respondents were asked which conditioning areas should be prioritised for young developing fast bowlers as opposed to a senior fast bowler during different phases of the season – see Table 5. Additionally, they were asked to rank the importance (1 most important – 4 least important) if there was a difference depending on what phase of the season they were in (off-season, pre-season, in-season)? It was suggested that skinfolds (anthropometry) and flexibility were areas that could be worked on regardless of development level and the time of the season and thus were not included in Table 2. Also omitted from Table 2 is power for reasons discussed earlier.

It would seem from Table 2 that strength training should be the major priority throughout the entire year, even if this is at the expense of all other conditioning areas. There is a focus on improving strength during the off and pre-season without gaining non-functional mass (Karppinen, 2010b). In-season training then concentrates more on maintaining (Table 3) those strength gains that have been achieved. This is easily achieved during the off and pre-season as the time restraints due to playing commitments are limited, but this is far more of an issue during a busy in-season. From Table 4 and previous research (RØNnestad, Nymark, & Raastad, 2011) it would seem that fast bowlers need to achieve one high intensity strength session every 7-10 days to maintain those strength levels.

Table 2 follows a classic linear periodization plan in that as volume decreases, intensity increases and there is a progression from the aerobic, anaerobic lactic to alactic system training through the off-, pre- and in-season (Pinto, Alves, da Silva, & Gomes, 2009; Stoppani, 2006). Although this type of periodization is good in theory, in many cases at the international level the schedule does not allow for a sufficient pre- or off-season to be

undertaken every year. Bowling loads or workloads involve increasing the volume and intensity while avoiding a spike (significant jump) in loads leading to the in-season (Dennis et al., 2003). Finally comments were given by the expert's suggesting that although the running intensity does increase as bowlers get closer to the in-season the volume cannot. As stated previously by Peterson et al. (2010,2011,2012), bowlers cover a significant amount of distance and the volume of training needs to match the game based volume to avoid a spike and injury (Dennis et al., 2004). Although a classic linear progression model can be followed, strength and conditioning specialists need to be flexible and react/plan to compensate for the training/workload demands of the players.

Another interesting finding was that the conditioning priorities throughout the entire season are the same for all bowlers regardless of the developmental level (see Table 2). Although the experts did express that this again depends largely on the individual bowlers strengths and weaknesses. It would seem that there is a basic pattern that should be followed around what conditioning areas require focus during the different phases of the year.

Table 6: The conditioning areas that can be improved during the in-season.

	Cannot maintain	Can maintain	Can improve
Strength	21.6%	68.6%	9.8%
Speed	7.8%	41.3%	49.0%
Aerobic fitness	7.8%	68.6%	23.5%
Anaerobic fitness	7.8%	64.7%	27.5%
Body fat	5.9%	31.4%	62.7%
Flexibility	3.9%	41.2%	54.9%

The major observation from Table 6 is that very few experts believed that you could not maintain or even improve any of the conditioning areas during the in-season. Strength was the only area where a substantial percentage (21.6%) of the expert's suggested that it could not be maintained during the in-season. However, the majority (68.6%) still believed strength could be maintained.

Many international and domestic schedules only have 1-3 days in-between fixtures. A large amount of this time for fast bowlers needs to be spent recovering from the extreme distances, intensities and pressures that their bodies have had to endure. For this to occur careful consideration needs to be given to how many conditioning sessions need to take place and secondly what intensity they need to occur at in order to maintain the specific

fitness components through the season. Once this is understood the actual game loads and associated stresses need to be understood so as these stimuli can be incorporated in a maintenance program.

Table 7: Sessions and intensity needed to maintain conditioning levels.

	Number of sessions (Per 10 days)	Intensity of sessions (10 = highest intensity)
Strength	1	8
Speed	1	8
Aerobic fitness	1	8
Anaerobic fitness	1	7
Flexibility	4	6

As an adjunct to Table 7 the experts were asked how many sessions per 10 days and the session intensity required for the maintenance of fast bowlers fitness. According to the experts most conditioning areas can be maintained with very few sessions as long as they were performed at high intensity. Consequently the maintenance of these fitness components would seem easy to achieve with good planning. The one area that needed more frequent sessions (flexibility) involved minimal time and fatigue on the body (Leon, Oh, & Rana, 2012) and could easily be incorporated into a players schedule during down time, in the game itself or during practices.

It can be observed from Table 8 that strength is believed to be the only fitness component that cannot be improved via playing the actual game of cricket. All other fitness components can be covered by playing the game. For example, speed is covered through the bowler's run-up and fielding, anaerobic fitness through the repeated sprints of bowling and fielding and aerobic fitness through the distances that are covered through bowling and fielding. This places a priority around planning and implementing specific strength session/s in the athlete's schedule every 10 days. It appears that the experts think all the other fitness components listed in Table 5 can be improved by playing the game. However, it needs to be noted that this does not guarantee that all of these components will be covered in every game, rather they can be covered depending on the workload of the game e.g. a ODI is being played in spin friendly conditions and fast bowlers are not required to bowl their full quota of overs. Therefore the specific loads or work that a bowler achieves in each individual game needs to be monitored so that extra sessions can be implemented as required.

Table 8: Conditioning areas that can be improved through game play.

	Yes	No
Strength	9.8%	90.2%
Speed	72.5%	27.5%
Aerobic fitness	86.3%	13.7%
Anaerobic fitness	80.4%	19.6%

Body specifics

The opinion of what strength qualities need to be addressed to best enable fast bowlers to withstand the significant forces that are placed on their bodies (Elliott et al., 1993; Elliott & Foster, 1984; Elliott et al., 1986; Elliott et al., 1992; Foster et al., 1989; Hurrion et al., 2000; Mason et al., 1989; Portus, Mason, et al., 2004) are detailed in Figure 1. Furthermore there are different strength requirements for different areas of the body i.e. 76.4% of participants agreed that different areas of the fast bowlers' body (lower versus upper body) require different types of strength training. For example, increasing maximal strength via neuronal training methods for the upper body where strength gains are needed without mass gains, versus hypertrophy training methods for the lower body where some mass gains are acceptable when trying to increase strength (Karppinen, 2010a). Most experts (96.4%) agreed that non-functional mass was an injury risk to the fast bowler. Non-functional mass can be classified as extra body fat or extra muscle mass that is not contributing to performance (Karppinen, 2010b). Excess fat mass increases the ground reaction forces that the bowler has to withstand and most likely therefore increases the likelihood of injury. Furthermore, excessive muscle mass in the upper body will not only magnify the ground reaction forces and therefore increase injury risk, but may also alter technique mechanics. Rather than using effective summation of segmental velocities from lower body through to the bowling arm, the bowler may have a tendency to rely on the upper body strength to try and produce ball speed. This reliance on upper body strength has been thought to increase spiral torsion through increased counter-rotation, thereby placing the bowler at greater risk of lumbar spine injury (Foster et al., 1989; Portus, Mason, et al., 2004). This is not suggesting that bowlers do not need to be strong or have a concentration on strength in the upper body. Expert opinion and previous researchers (Wilk, Meister, & Andrews, 2002) have suggested that upper body strength and symmetry are very important but not at the sacrifice of gaining extra mass and losing flexibility.

Figure 3: Strength areas that are most important to fast bowlers.

■ Maximal Strength ■ Hypertrophy ■ Strength Endurance
 ■ Relative Strength ■ All Strength Areas

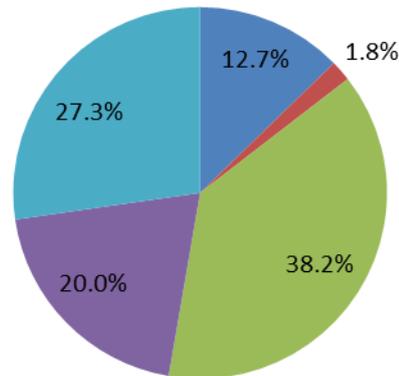
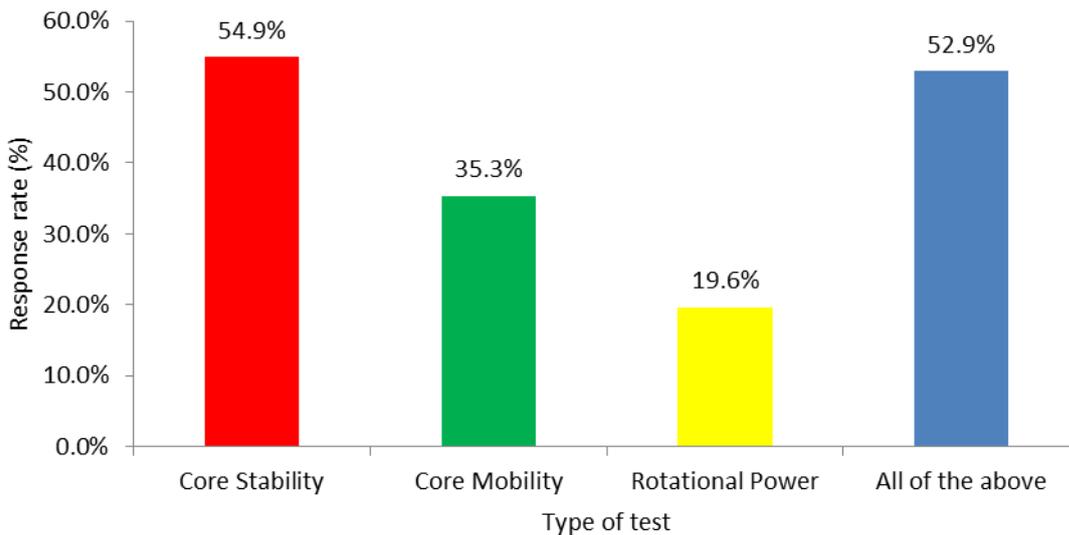


Figure 4: Experts opinion on the importance placed on different areas of core strength.



In Survey 1 the experts expressed that core strength and testing core strength was very important for fast bowlers. The term “core strength” is very vague and has many different components and definitions (Hibbs, Thompson, French, Wrigley, & Spears, 2008). Therefore in Survey 2 the experts were asked to elaborate on this quality and give an indication of the importance of each area. The responses can be observed in Figure 4. It seems that all of these core components are important for the fast bowler in varying degrees. There is a real need for a better understanding of the role that the core plays for the fast bowler during the bowling action and other aspects of the game. This should be the focus of further research to understand how these different components correspond to injury prevention and

performance. Strength and conditioners could then be more specific about the way these areas are conditioned.

In summary, more in-depth research is required around strength and how it relates to fast bowlers. Some questions that warrant further investigation include what type of strength is most beneficial (relative strength versus strength endurance etc.), what muscular actions to train (eccentric, concentric and isometric), how much strength is needed in the lower body relative to the specific demands of individual bowlers and do all of these factors vary with specific body types and bowling actions?

Assessments

The previous sections have given some insight into expert opinions of the physical requirements of fast bowling and the strength qualities that are important. The next section of the survey inquired about the alignment of appropriate assessment tasks to the fitness components of interest. Most experts (80.4%) believed that the field based tests should be modified depending on the development level of the athlete. Comments suggested that this finding mainly relates to field based strength tests, namely novice athletes should firstly use a predicted 1 repetition maximum (1RM) strength test then as their training age improved they could progress to true 1RM testing.

Strength

The experts preferred 1 RM testing or estimated 1 RM testing (42.7%) methods for quantifying the strength of players across all formats of the game. Load assessment (18.8%) and maximum rep testing (20.8%) were also highlighted as common assessments. Experts expressed that load assessment (having an athlete lift maximally for one set in their normal gym session, then using a predicted 1 RM calculation to produce a score) would mainly be used during an in-season playing phase where it can be hard to find time for athletes to find time to train or test. Load assessment allows both to be achieved during the same session. As long as they are lifting maximally this is a good way to get an indication on how a player's strength is being maintained/decaying between games. Static or isometric testing (7.3%) and isokinetic testing (10.4%) did not feature significantly.

Aerobic

The Yoyo intermittent recovery test where the athletes run 20 meter shuttles at increasing speeds with a 10 second active recovery at the end of every second shuttle, was considered the field based test that the experts considered most appropriate to assess aerobic fitness (Tests/multi day games - 46.4%, ODI's/1dayers - 60.7%, Twenty20 - 67.9%). The Yoyo

endurance test which is similar to the well-known beep test where athletes run 20 metre shuttles at incremental speeds continuously, was the only other test to significantly rate as a test that could be used for Test/Multi day games (25.0%).

Anaerobic

The sprint fatigue test where 10 times 30 meter sprints are conducted at 30 second intervals with a fatigue index calculated as a score was considered the most relevant test (38.9%) to assess the anaerobic component of fast bowlers across all formats of the game (Test/Multi day games 40.0%, ODI's/1dayers 35.7%, Twenty20 41.1%). Other tests that had significant ratings included the anaerobic sprint test (RAST, 19.2%) where the athlete performs 6 sprints over 35 metres with a ten second recovery which provides measurements of peak power, average power and minimum power along a fatigue index. Another identified test was the phosphate recovery test (18.0%) which involves 7 maximal sprints of ~7 seconds with a 23 second passive recovery between each sprint where the drop-off distance between each sprint is recorded.

Speed

The distances that were seen as specific for speed testing within cricket were 5, 10, 20 metre sprints (30.4%), and 10, 20, 30 meter sprints (25.6%). However, this did vary across the different formats of the game with 10, 20, 30 meter sprints (30.4%) being preferred over 5, 10, 20 meter sprints (21.4%) in Tests/Multi day games. Conversely, 5, 10 and 20 meter sprints were preferred in ODI's/1dayers (32.1%) and Twenty20 (37.5%) as opposed to 10, 20, 30 meter sprints in ODI's/1dayers (26.8%) and Twenty20 (19.6%). There were comments reflecting that the 5 meter or even 2 meter distances need to be covered in testing to assess "speed or power off the mark".

These results are confusing when related to the responses given in Survey 2 when the experts were asked if measuring 5, 10 and 20 meter sprints could be compared or related to the bowler's run-up. Fifty eight percent of the experts suggested that it did not relate as players needed to be able to attain their maximum velocity for comparison. Although literature suggests that a athletes maximum velocity can be reached within 20 metres (Mendez-Villanueva et al., 2011) it was believed that most fast bowlers maximum velocity was not achieved in a 20 meter sprint. The above results and comments would suggest that a shorter distance of around the 5 meter distance needs to be assessed along with a longer distance of around 30 metres. This would cover all aspects for all formats of the game.

Power

When the experts were asked about the best field tests to assess the “power qualities” of fast bowlers across the different formats of the game, the results were quite consistent between formats (2.2% variance) but quite varied between tests. The counter movement jump (19.5%) where an athlete firstly squats and then performs a maximal vertical jump, was the top ranking test but closely followed by the vertical jump (17.1%), performing a maximal vertical jump and the unilateral 3 hop test (16.5%) where an athlete performs 3 horizontal, single leg jumps for distance. Other (9.8%) tests included force plate testing and squat jumping. The final 37.1% of responses were made up of many different individual tests (bilateral 1, 2 and 3 jumps, Olympic lifting, squat jump, unilateral single hop, drop jump), but none of these ranked significantly. Of interest was that the only upper body power test that was mentioned by any of the experts was “a throw test”. This may be due to the survey structure where the options to choose from did not include specific upper body power tests. The only area where they could be included was in the comments section. As stated earlier a gap in the research exists and requires further investigation to understand the contribution of the core and upper body to the bowling action but there is no doubt that upper body power plays a significant part in other areas of the fast bowlers game e.g. throwing and batting (Marques, Van Den Tillaar, Vescovi, & González-Badillo, 2007; O’Shea, 1991; Taliep, Prim, & Gray, 2010)

Anthropometry

Skinfolds (49.4%) were considered the most important anthropometric quality to measure in fast bowlers and this was consistent with a 1.8% variance across the 3 formats. No mention or comments were made of how many sites and what the main sites of importance were. The most common answer was “All of the above” and included using skinfolds, weight, girth measurements, body mass index and limb measurements (32.1%) to build an anthropometric profile of the athlete. This is consistent with previous research where the specifics of the best way to formulate a whole body anthropometric profile for a fast bowler were not mentioned. What researchers have suggested is that leaner body statures are desirable for performance (Portus et al., 2000) and decreased injury rates (Dennis et al., 2003). Given this consensus the specifics need to be identified that best map the important anthropometry of fast bowlers e.g. amount and sites for skinfold measures, limb lengths, etc.

Flexibility

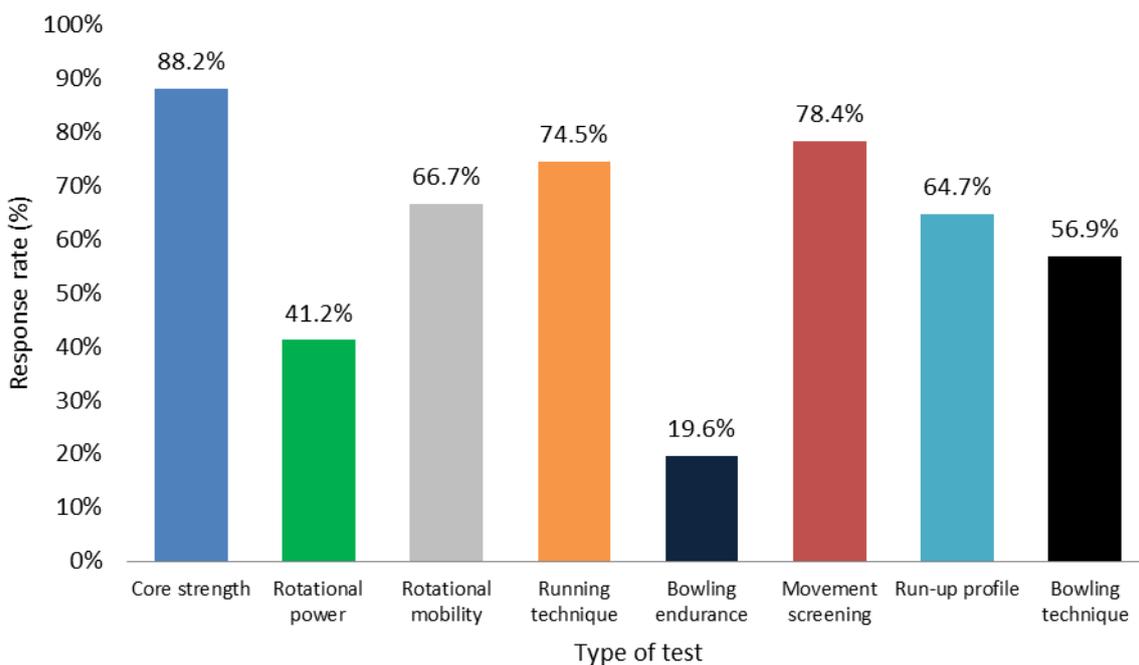
When asked the specific areas of the body where fast bowlers should concentrate on flexibility, the areas that were repeatedly commented on were ankle dorsiflexion, hamstring,

hip and shoulder regions. Specifically reduced range of motion has been linked to increased injury risk (Dennis, Finch, Elliottc, et al., 2008). However, it was suggested that although these were the main areas this would largely depend on the specific requirement of the individual. Previous researchers have suggested that general whole body flexibility is important for the fast bowler with a specific focus on the areas of lower lumbar and hamstrings (Johnstone & Ford, 2010; Patel et al., 2002), so the survey results provide a little more additional information in this area

Other tests

During Survey 1 it was suggested that additional tests need to be included in the testing battery. The specific tests that were mentioned were: core strength, rotational power, rotational mobility, running technique, bowling endurance, movement screening, run-up profile and a bowling technique assessment. Survey 2 was used to determine the importance of each of these suggestions, the results of which can be observed in Figure 5.

Figure 5: Importance (%) of other tests in the assessment of fast bowlers.



The movements that the experts thought most useful for specific cricket movement screening can be observed in Table 6. These do not cover all movements that are needed in the gym or in the general movement of the athlete but they have been suggested as being the most relevant for fast bowlers.

The run-up of the fast bowler and its contribution to performance has been the focus of a great deal of research (Duffield et al., 2009; Elliott & Foster, 1984; Glazier et al., 2000; Salter et al., 2007), the researchers suggesting that the run-up has a contribution to the performance and ball release speed of the bowler. More specifically Duffield et al. (2009) reported a moderate to strong correlation ($r = 0.70$) between the speed that a bowler was able to maintain through the final 5 metres of their run-up and peak/mean ball speed (Duffield et al., 2009). Furthermore not only can the bowling technique/action be affected by the run-up of the bowler but the action itself has a major influence on injury and performance (Elliott & Foster, 1984; Elliott et al., 1986; Ferdinands & Kersting, 2007; Ferdinands, Kersting, et al., 2010; Salter et al., 2007). The experts in this research agreed that a run-up profile and a bowling technique assessment were very useful; however these assessments require equipment (GPS, Radar, etc.) and/or a skills coach, which is not always practical.

Although a bowling endurance assessment (an assessment where fast bowlers bowl at maximum velocity for as long as possible) was suggested by Survey 1 respondents, when it was investigated further it was not rated as significantly important (19.6%). In support of this 53% of all responses from all experts stated that a bowling endurance test was not practical, 25% were not sure and 22% suggested that it was practical. Respondents suggested that for this to be accurate the bowler would have to run in and bowl at full intensity every delivery. This is not relevant to the game and could potentially be an injury risk as bowlers have not progressively built their bowling loads to this amount of load and intensity. If the bowler does load to this level then the bowler is loading specifically to complete the test as bowlers do not need to load to the same extent for games. This could mean a spike in bowling load and therefore an increased injury risk (Dennis et al., 2004).

Table 9: Top 5 ranked movements thought most important to be assessed for fast bowlers.

Movement:	Ranking
Single leg squat	1
Sprinting	2
Squat	3
FMS shoulder mobility test	4
Rotation	5

An area where young developing fast bowlers and senior bowlers do differ and a significant finding of this survey was the answer to the question “whether or not a young fast bowler should be pushed to keep bowling fast while they are developing the physical attributes

needed to deal with the pressures of fast bowling or they should back off?" A significant amount of experts (76.8%) believed that the young fast bowler should push on and keep bowling fast. The explanation around this was stated to be that "if they do not use it they will lose it". That is, if a young bowler continually bowls at a sub maximal level then they will not be able to withstand the substantial pressures on the body that are pre-requisite of bowling fast. Their body still needs to learn the specific bowling action at full intensity e.g. bowling fast. With this in mind, it is strongly suggested by the experts in the majority of comments that strict supervision of the amount of bowling undertaken at high intensity should be monitored and carefully planned. Therefore the guidelines that have been suggested by numerous researchers in this area (Dennis et al., 2004; Dennis et al., 2003; Dennis, Finch, McIntosh, et al., 2008; Orchard et al., 2006; J. Orchard et al., 2009) should be adhered to strictly but not to a degree where these developing fast bowlers are being restricted to such an extent where they are not bowling maximally.

Conclusion

The results of this research give some insight into the specific and unique physical requirements of cricket fast bowling. This paper has provided a consensus of expert's opinions to address this issue and give some guidance to strength and conditioning coaches around best practice. A summary of the best field based tests identified by the experts in each conditioning quality can be observed in Table 10. By carrying out these tests the strength and conditioning coach should have a full profile of the bowler that guides their conditioning programming. A better understanding is needed on what function the core plays during the bowling action, therefore further research needs to be undertaken around core assessment and conditioning practice that guides the development of the fast bowler.

Table 10: Summary of the field based tests suggested by the experts.

Conditioning Quality	Tests
Aerobic fitness	Yoyo intermittent recovery test
Anaerobic fitness	Sprint fatigue test
Speed	5, (10 or 20),30 meter sprint times
Power	Counter movement jump, vertical jump or unilateral triple jump, a rotation power assessment
Strength	1 rep max testing or estimated 1 rep max testing, a core strength assessment,
Anthropometry	Skinfolds
Flexibility	Ankle dorsiflexion, hamstring, hip and shoulder regions, a rotational mobility assessment
Specific testing	A run-up profile, a bowling technique assessment

The fitness quality that was deemed to be most important for fast bowlers regardless of developmental level and time of the year was strength. There are different focuses on strength depending on the time of the year, developmental level and physical stature of the specific athlete e.g. hypertrophy versus relative strength or improving strength versus maintaining strength but results show there should always be a priority of a strength focus within the conditioning program of the fast bowler. Other fitness qualities follow a classic linear periodization plan where as volume decreases, intensity increases and there is a progression from the aerobic, anaerobic lactic to alactic system through the off-, pre- and in-season.

It is usual practice that the levels of the fitness qualities drop or decrease during an in-season. The results from this research suggest a formula where the high levels of conditioning that are required for fast bowling can be maintained through the busy competitive phase of the in-season. This can be achieved through suggestions that all fitness qualities, apart from flexibility (4 medium intensity sessions every 10 days), only need one high intensity session every 10 days to maintain them. Furthermore the experts have suggested that the fitness qualities of aerobic fitness, anaerobic fitness, speed and power can be covered (depending on the specific load undertaken) via playing the game. This would mean that as long as the game loads were monitored closely and these qualities were covered during the game a fast bowler would only need to schedule one high intensity strength session and four medium intensity flexibility sessions every 10 days to ensure that all fitness qualities were maintained during the in-season.

THESIS SUMMARY

The sport of cricket is unique in the fact that it has three different formats in which the workload and intensities of the athlete's vary greatly. The physical preparation for players needs to address many fitness components and the transition between formats needs to be planned very carefully as quite often player's transition between the three formats of the game is undertaken in short periods of time (or in 1 competitive series or similar).

Injury prevalence was higher in pace bowlers than any other position in cricket. Multi-day cricket sustained the highest percentage of injuries of all the formats. Injury prevalence has gradually increased in line with increases in scheduling of games. How T20 cricket will affect the injury rates of fast bowlers will largely depend on how these matches are scheduled. If there is no reduction in multi-day and one-day cricket and hence the schedule simply becomes more cluttered, there is no doubt there will be an increase in injury rates if player rotation policies are not implemented. However, if there is a reduction in other forms of cricket or player rotation is introduced to allow more T20 cricket to be played, then the injury rates of fast bowlers will be reduced as they do not get injured as much in T20 cricket. Careful consideration to bowling workload plans, especially early in the season, needs to be a focus of coaching staff.

The vertical ground reaction forces through the front foot of the delivery stride are between 3.8-12 times body weight, with braking mean peak forces between 1.4 and 2.5 times body weight. Higher ball release speeds have been linked to faster approach speeds and a straighter front leg at delivery. Given this information, it would seem that increasing the run-up velocity of the fast bowler could be a desirable adaptation, provided other aspects for the bowling action and performance outcomes are not compromised. There also needs to be a concomitant increase in the strength of the trunk and leg musculature to absorb the probable increase in peak vertical and horizontal ground reaction forces.

The assessment of fast bowlers at the basic level needs to cover all the aspects of conditioning that they encounter. Largely the assessment battery covers the general conditioning principles of strength, power, speed, aerobic, anaerobic as well as anthropometric and flexibility aspects.

From the information presented it would seem that after completion of a general training program where bowlers have had a focus on strength (including power and eccentric training), aerobic conditioning, anthropometric and flexibility aspects, bowlers should focus on developing lower-body speed (explosive and repetitive) and anaerobic upper-body power. Greater flexibility around the lower lumbar and hamstrings could be needed within the bowling group because of the technical movements that occur during bowling delivery. Attention needs to be given to the ideal anthropometry of the fast bowler. Theoretically, given the exact same bowling action, the vertical GRF of a lighter bowler should be less since force is the product of mass and acceleration. Following this logic it would be beneficial for the fast bowler to be as lean as practical to reduce the GRFs they have to endure during an over, innings and game. This can be achieved through reduction of fat or through the reduction of unwanted muscle mass. Careful consideration needs to be given to functional mass changes and the anthropometric blueprint for the fast bowler.

The results of this research give some insight into the specific and unique physical requirements of cricket fast bowling. This thesis has provided a consensus of expert's opinions to address this issue and give some guidance to strength and conditioning coaches around best practice. A better understanding is needed on what function the core plays during the bowling action.

The fitness quality that was deemed to be most important for fast bowlers regardless of developmental level and time of the year was strength. There are different focuses on strength depending on the time of the year, developmental level and physical stature of the specific athlete e.g. hypertrophy versus relative strength or improving strength versus maintaining strength but results show there should always be a priority of a strength focus within the conditioning program of the fast bowler.

It is usual practice that the levels of the fitness qualities drop or decrease during an in-season. The results from this research suggest a formula where the high levels of conditioning that are required for fast bowling can be maintained through the busy competitive phase of the in-season. This can be achieved through suggestions that all fitness qualities, apart from flexibility (4 medium intensity sessions every 10 days), only need one high intensity session every 10 days to maintain them.

CHAPTER 5: SUMMARY, PRACTICAL APPLICATIONS AND FUTURE RESEARCH DIRECTIONS

Introduction

The role that the physical condition of fast bowlers plays in terms of performance and injury prevention has been of concern for strength and conditioning coaches, physiotherapists, sports doctors, coaches, commentators, journalists and administrators. Little scientific attention has been undertaken in the area and therefore the implementation of conditioning programmes with a focus on performance and injury prevention can only rely on task analysis, educated opinion and best practice from other sports.

Based on the review of literature and the findings of a series of surveys that were used to determine if there was a consensus of opinion amongst “experts”, the following practical applications have been suggested. The proposed structure for the strength and conditioning of the fast bowler is outlined in Figure 1. Athlete progression within this framework is achieved by the fast bowler achieving various milestones rather than spending a certain time within a training cycle i.e. once an athlete achieves a specific conditioning goal they then progress, regardless of time. Different athletes will enter the program at different levels with different strengths and weaknesses. If the program is time focused rather than milestone focussed there is a risk of either inhibiting player development by progressing their development prior to achieving a desired level or conversely players spend time within a level that is too easy for them. In summary, the central intent of the program is that athlete readiness determines progression and overload in a sequential manner.

STRENGTH AND CONDITIONING OUTLINE FOR FAST BOWLERS

Movement competency, anthropometry and flexibility provide the initial focus of any fast bowling strength and conditioning program. These areas can be developed concurrently and at different levels and tempos without impacting on each other to a significant level. In fact it is thought that the impact of training concurrently in these areas is most likely positive e.g. an increase in flexibility can help with improved movement competency (Kritz, Cronin, & Hume, 2009) and excessive non-functional mass can hinder cardiovascular development (Czajkowska, Mazurek, Lutostawska, & Źmijewski, 2009). In summary, these three components can be developed concurrently without excessive negative impact on the athlete.

Movement competency

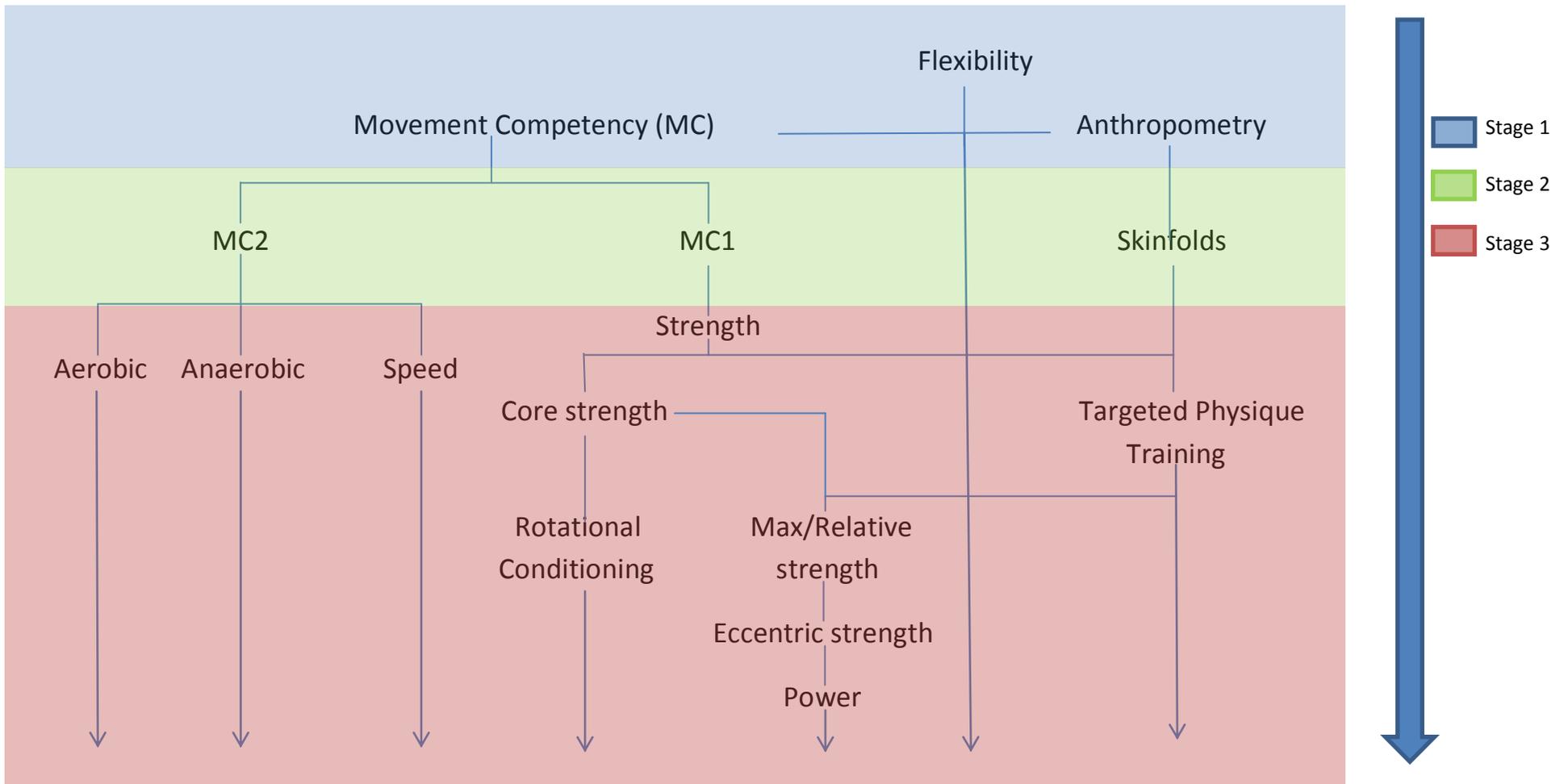
Optimal movement or movement competency can be described as movement that occurs without pain or discomfort and involves proper joint alignment, muscle coordination and posture (Cibulka & Threlkeld-Watkins, 2005; Kritz et al., 2009). Without optimal movement joint function will suffer and performance may suffer (Kritz et al., 2009). The expert's consensus for the movements that are most specific and important to fast bowlers are detailed in Table 11. The profile gained by the athlete going through a movement screening that involves the below movements provides the strength and conditioning coaches with a specific fast bowling strength and conditioning program that is aimed at physically preparing them for the loads and demands of international cricket. If the athlete has dysfunction in any of these movements then prescribing corrective exercises should be the first action taken.

Table 11: Top 5 ranked movements thought most important to be assessed for fast bowlers.

Movement:	Ranking
Single leg squat	1
Sprinting	2
Squat	3
FMS shoulder mobility test	4
Rotation	5

Figure 7: Conditioning outline for a fast bowler

Development



Movement Competency 1 (MC1) = Single leg squat, squat, FMS shoulder mobility test, rotation.

Movement Competency 2 (MC2) = Single leg squat, sprinting.

Anthropometry

Appropriate sums of skinfolds were considered by the experts as very important for fast bowlers. Some experts even suggested that this was the most important aspect for the athlete to focus on. This was based on the premise, that optimal anthropometry requires the athlete to be disciplined around diet and exercise the majority of time and if they are achieving this then the chances are that they will be achieving results in other areas.

The initial anthropometric focus of a developing fast bowler is to reduce undesirable fat mass via diet and for some potential bowlers in conjunction with strength or cardiovascular training. If the skinfolds of a fast bowler are too high it means they have non-functional mass that can negatively affect performance and add to the likelihood of injury. If a fast bowler's skinfolds are too low then the fat stores cannot be used as an energy source to aid in the substantial distances that a fast bowler needs to cover in test matches or ODI's (Petersen, Portus, et al., 2009; Petersen, Pyne, Dawson, et al., 2011; Petersen et al., 2010; Petersen, Pyne, Portus, et al., 2011; Petersen, Pyne, Portus, et al., 2009). There are a minimal amount of fast bowlers that only play in the shortest format of the game (T20). However most bowlers that play the T20 format of the game play at least the ODI's and potentially all three formats of the game.

Skinfolds are a conditioning area that the experts considered can be improved in conjunction with other conditioning areas and regardless of the phase of the season. Careful consideration needs to be put into how this can be improved if a bowler is in a competitive phase as rapid weight loss can cause reduced performance (Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002). Professional help from a nutritionist should be considered in order to ensure no loss of performance during this phase.

As can be observed in Figure 7 once the desired skinfolds have been achieved the focus of the programme shifts to optimising lean muscle mass through diet and strength training. It is important that this is not undertaken until the desired milestones have been achieved under the strength heading in Figure 7. The desired body stature for a fast bowler is lean in the upper body without too much muscle mass. Extra non-functional mass in the upper-body including extra muscle mass will most likely not improve performance but can increase the likelihood of injury (Karppinen, 2010b). The bowler still needs to be strong and have a

strength balance through the upper body but these strength gains most likely need to be neural enhancing the relative strength/power of the bowler (Gabriel, Kamen, & Frost, 2006; McGill & Karpowicz, 2009).

After these milestones have been achieved the last anthropometric focus is optimizing muscle mass through hypertrophy training in specific areas. The lower-body still needs to be lean but can afford to have a little more muscle structure if this aids to increase strength or power that can in turn aid performance or injury prevention. Strength in the lower body is key in numerous ways. Firstly if a bowler is going to withstand the substantial forces that their body has to endure (Elliott et al., 1993; Elliott et al., 1992; Hurrion et al., 2000; Portus, Mason, et al., 2004) they need to be strong. Secondly, increased leg strength has a direct correlation to increased running velocity (Bret et al., 2002). Increased running velocity can assist the bowler's run-up velocity, which in turn is known to be a performance benefit to bowlers (Duffield et al., 2009; Ferdinands, Kersting, et al., 2010; Ferdinands, Marshall, et al., 2010; Salter et al., 2007), Slight increases in muscle mass to aid strength gains (S. McGill, 2004) in the areas of the fast bowlers body (lower body) that contribute to increased performance and injury prevention are therefore acceptable. However, it needs to be noted that a needs analysis should identify the bowlers strengths and weaknesses and it could be that for some bowlers strengthening of the upper body is the focus of much training.

Flexibility

Like anthropometry this is a conditioning area that can be integrated into the training program of the bowler regardless of the phase. Although relatively simple to integrate, this component needs regular attention, as this component is often forgotten in the conditioning of the bowler. The importance with regards to injury prevention (Gabriel et al., 2006) and increased performance (S. McGill, 2004) of flexibility to the fast bowler should not be underestimated as this has been proven in other sports.

The long-term focus of the bowlers flexibility programme is to simply increase the flexibility and range of motion in the specific areas of ankle dorsiflexion, hamstring, and hip and shoulder regions. These are the areas that experts suggested are the most important to have an optimal range of motion. Reduced ankle dorsiflexion range of motion and more specifically large changes in this range of motion have been shown to be an increased risk for injuries to fast bowlers (Dennis, Finch, Elliottc, et al., 2008). Hamstring, hip and groin

regions logically are also areas of risk due to the nature of the run-up and bowling action (Dennis, Finch, McIntosh, et al., 2008; Fong, Blackburn, Norcross, McGrath, & Padua, 2011).

The rest of the programme then is concentrated around maintenance of flexibility or improvement in areas that are specific to the individual. To achieve this it is recommended that bowlers regularly (daily) engage in flexibility programs that address their individual needs. This needs to be an area that constantly needs to have a focus throughout a bowler's career. A combination of static and dynamic stretching needs to be adopted following the general guidelines associated with warm-ups and recovery. However, if the individual needs to increase flexibility then regular static stretching has been suggested as the method of choice (McGill & Karpowicz, 2009).

Movement competency

It can be observed from Figure 7 that movement competency has been split into two different pathways MC1 (single leg squat, squat, FMS shoulder mobility test, rotation) and MC2 (single leg squat, sprinting). The competencies of MC1 need to be achieved in order for the fast bowler to progress to strength training, likewise the competencies of MC2 need to be achieved for the fast bowler to progress to aerobic, anaerobic or speed training. If any of the competencies are not achieved, then the problem areas become the main focus of their program. It is imperative that such an approach is taken as these competencies provide the foundation for most of the movement patterns important to the fast bowler.

As shown in Figure 7 different aspects of the conditioning program can be performed in conjunction with each other. For example, if the competencies associated with MC2 have been achieved then the bowler can progress with their strength training in conjunction with anthropometric, flexibility, aerobic, anaerobic and speed training. If MC2 has not been achieved then the player must continue with the strength, flexibility and anthropometry focus.

Strength development

It is important to note that the experts thought strength development was the most important conditioning area for a bowler to concentrate on regardless of the development level and

time of the season. Once the MC1 milestones have been achieved, strength development can occur as outlined in Figure 1. A movement screening progression should be followed at all times in conjunction with the bowler's development and regardless of the milestones. This simple progression has a core focus of the bowler performing the correct movement pattern. This starts with assisted work and then progresses to body weight, resisted, eccentric and then plyometric exercises.

Technique

As stated without achieving MC1 competencies the athlete could be restricted as to the level of strength development that they can potentially achieve. However, this is not the only perceived movement competency that needs to be achieved for strength development. Technical proficiency in the specific exercises that are used in the conditioning program is fundamental and needs to occur regardless of the milestone, development level or time of the season. Even though the bowler has a good squat pattern which has been assessed through MC1 their deadlift technique may not be to a standard where the movement can be loaded. The aim of every session is to optimise the exercise technique/movement efficiency of the bowler. To achieve this careful attention and targeted feedback is needed.

Core strength

The core musculature can be described as the pairs of muscles that support the lumbo pelvic hip complex in order to stabilize the spine, pelvis and kinetic chain during functional movement (Faries & Greenwood, 2007). Core strength can be defined as the ability of the musculature to stabilize the spine as a platform for body movement (Faries & Greenwood, 2007). This therefore suggests that you cannot have core stability without core strength. They are a bi-product of each other. Core strength has been suggested by the experts as extremely important to fast bowlers (Feros et al., 2012; McGill & Karpowicz, 2009).

A suggested progression for undeveloped fast bowlers is to start with simple spinal/hip stability exercises as shown in Tables 12 and 13. First strength endurance needs to be built through these simple exercises to a level where bowlers are reaching an adequate standard for the general population. An example of this can be suggested around one minute in front bridges and 45 seconds on side bridges. Once this has been achieved more of a strength focus through more of the complex exercises can be applied where the bowler is only working for 15-30 seconds but modifications are made to the exercises where the bowler is made unstable, they have greater distance between limbs or a ab wheel is introduced where the bowler lies prone and extends the wheel beyond their head, staying long and strong.

Once the above targets have been achieved a more whole body core conditioning focus needs to be followed while undergoing general strength work and exercises such as shown in Tables 12, 13 and 14 with the complex exercises (Read, 2013; Williardson, 2007). A focus during the whole body strength work needs to be placed on the core and when the core becomes unstable, this is the failure point of the exercise e.g. if performing a standing military press the point of failure is when the bowler loses neutral spine or normal posture, even if they could carry on with more reps due to their shoulder strength. If this philosophy is followed then limb strength and core strength will be developed in conjunction with one another.

Core strength is similar to flexibility in that this is an area that needs future research attention. There is a real need for a better understanding of how conditioning the core affects fast bowling. Once we understand how conditioning the core affects injury prevention and performance, strength and conditioners can be more specific about the way these areas are targeted. As it stands it is acknowledged that the core of the fast bowler needs to be very well conditioned but to what level and what the best assessments are, is yet to be understood.

Table 12: Spinal related core exercises.

Simple Spinal Stability Exercises	Examples
Anti-Spinal Extension/Anti-Anterior Pelvic Tilt	Push ups, front planks, ab wheel rollouts
Anti-Spinal Lateral Flexion/Anti-Lateral Pelvic Tilt	Side planks, suitcase holds
Complex Spinal Stability Exercises	Examples
Anti-Spinal Extension/Anti-Anterior Pelvic Tilt	Ab wheel rollouts
Anti-Spinal Flexion/Anti-Posterior Pelvic Tilt	Squats, deadlifts, farmer's walks
Anti-Spinal Lateral Flexion/Anti-Lateral Pelvic Tilt	Suitcase holds
Simple Spinal Flexion/Extension Exercises	Examples
Spinal Extension/Anterior Pelvic Tilt	Supermans
Spinal Lateral Flexion/Pelvic Lateral Tilt	Side bends
Spinal Flexion/Posterior Pelvic Tilt	Crunches, reverse crunches
Complex Spinal Flexion/Extension Exercises	Examples
Spinal Extension/Anterior Pelvic Tilt	45 degree spinal extensions
Spinal Lateral Flexion/Pelvic Lateral Tilt	45 degree side bends

Table 13: Hip related core exercises.

Simple Hip Stability Exercises	Examples
Anti-Hip Extension	Band psoas holds
Anti-Hip Flexion	Standing cable chest presses, half-kneeling anti-rotation presses
Anti-Hip Abduction/Adduction	Side planks
Anti-Hip External/Internal Rotation	Pallof presses
Complex Hip Stability Exercises	Examples
Anti-Hip Extension	Bulgarian split squat (rear leg)
Anti-Hip Abduction/Adduction	Top leg elevated side planks
Simple Hip Flexion/Extension Exercises	Examples
Hip Extension	Squats, deadlifts, hip thrusts
Hip Flexion	Cable standing hip flexion, ankle weight standing hip flexion
Hip Abduction/Adduction	Band standing abduction
Complex Hip Flexion/Extension Exercises	Examples
Hip Extension	Hang clean, power clean, snatch (Olympic style lifts)
Hip Abduction/Adduction	Band standing adduction, x-band walks
Hip External/Internal Rotation	Band standing hip rotation, band side lying clams

Rotational power

Once the desired level of core strength has been achieved rotational power needs to be developed. A suggested progression is to start with static, anti-rotation exercises (as shown in Table 14) They concentrate on the core muscles that are responsible for rotation. Then progress through to isolated rotational movements such as med-ball rotations that concentrate specifically on the core. The bowler can then progress to more whole body rotational exercises such as wood-choppers and finally concentrating on rotational power exercises such as med ball throws as shown in Table 14.

This should be a definite milestone that needs to be achieved in a developing bowler before they reach the rigours of a busy domestic or international schedule. A concentrated block

needs to occur during the off-season to help strengthen and prepare the musculature for the rotational aspect of bowling. This needs to either occur before a bowler starts their bowling loading progression or in conjunction with lower intensity bowling. A developed bowler needs to keep maintaining this throughout an in-season via med-ball throws in warm-ups and specific gym work but a large amount of the conditioning needed for rotational movement will be covered via the bowler simply bowling.

It would seem logical that as the bowling action requires large degrees of rotation, some form of rotational conditioning is fundamental for the fast bowler. However, the type of exercise, volume and intensity needed to condition the fast bowlers core, is largely unknown.

Table 14: Rotational related core exercises.

Anti-Spinal Rotation/Anti-Pelvic Rotation	Pallof presses, cable anti-rotation presses
Spinal Rotation/Pelvic Rotation	Cable chops, cable lifts, med ball twists and throws, javelin throws,

Targeted physique training

The amount of time that is spent on this stage of the model largely depends on the bowler's natural physique. As suggested by the experts the physique that is ideal for a fast bowler is very lean in the upper body with little excess non-functional mass (fat mass or non-functional muscle mass). If the upper-body does have excessive non-functional muscle mass then time should be taken to reduce this through a mixture of maximal strength training (to maintain neural strength), strength endurance training and nutrition to aid the reduction of that mass. The lower body still needs to remain lean without any non-functional mass; however this term "non-functional mass" has slightly different meanings when referring to the lower and upper body of a fast bowler. Extra muscle mass in the upper body contributes little to a fast bowlers performance (Karppinen, 2010b) and therefore is non-functional. Extra muscle mass in specific areas of the lower body (gluts, quadriceps, hamstrings and calves) has been suggested as aiding performance and injury prevention of fast bowlers. There is a performance benefit to fast bowlers having increased strength, which can increase run-up momentum and the ability to transfer that momentum through to ball velocity via a stronger front leg during the delivery stride. Furthermore, there are injury prevention benefits through these areas, increased strength giving the bowler an increased ability to absorb and

withstand the substantial ground reaction forces associated with fast bowling. This type of training is not ideal in-season due to the need for strength maintenance and recovery; therefore these training goals need to be planned early in the bowler's development or during the off-season of the more developed bowler.

Max/relative strength

Once the above targets have been achieved, the goal of the strength training program is to maintain (in-season) and/or increase (off-season) the maximal relative strength of the fast bowler. Although the consensus from the experts was that strength endurance was the most important strength quality for a fast bowler, it is the opinion of the author that due to the excessive ground reaction forces the stronger the bowler the better. Therefore relative strength / max strength should be a focus for most fast bowlers. By improving their strength and power per kg of body weight there should be favourable adaptation to both strength endurance and power, two strength qualities fundamental to successful fast bowling.

In-season max/relative strength training needs to be prioritised over all other conditioning qualities. Experts suggested this area is the only conditioning quality that cannot potentially be maintained via playing the game of cricket. Only one session of high intensity or multiple sessions of medium intensity strength work needs to be planned around a busy playing and training schedule every ten days to ensure strength maintenance.

An in-season program can be very basic and concentrate mainly on the lower body through larger compound exercises plus a menu of simple push and pull upper body exercises. Rep ranges and set numbers should be kept low to maximize neural strength maintenance (Gabriel et al., 2006) and to ensure a minimal amount of fatigue. Exercise induced muscle damage can have a very negative affect on performance (Akdeniz, Karli, DaşDemir, Yazar, & Yilmaz, 2012) but if the bowlers can maintain a consistency of training and intensity this should be minimal.

Eccentric strength

Most researchers have shown that eccentric resistance training has a number of advantages over concentric only training when considering increasing muscle strength and size but also resulting in greater damage and fatigue (Gois et al., 2014). Eccentric conditioning is also fundamental for the strengthening of the muscle connective tissue that is often forgotten about in general conditioning programmes. Connective tissue strengthens far slower than normal muscle and can cause injury concerns if muscle and connective tissue strength

levels are significantly different (Mahieu et al., 2008). Therefore it may be advantageous to incorporate concentrated cycles of eccentric strength training during the off-season. The performance benefits of efficient deceleration during the delivery stride are well understood and has received substantial investigation. If the front knee is extended during the delivery stride then it acts as a lever and has a positive influence on ball release speed. If it flexes then it acts as a shock absorber and has a negative effect on ball release speed (Glazier et al., 2000). Although a straight leg technique can produce greater ball release speeds it is also a potential injury risk. When the front leg is more flexed the muscle structure absorbs the energy or pressure that is being transferred. While that energy is lost in terms of performance it does mean that the bowler's ankles, knees, hips, back etc. does not endure the same load and therefore injury risk (Crewe et al., 2013; Portus, Mason, et al., 2004). Eccentric conditioning of the leg musculature can assist with injury prevention through preparing the bowler for the eccentric braking forces associated with the delivery stride. It can also help with increasing performance through potentially creating increased stiffness through the front leg in the delivery stride, keeping the bowler taller, which has been shown to increase ball velocity and ball release height. Careful consideration needs to be given to both the horizontal and vertical components of these eccentric braking forces.

Regardless of the developmental level of the bowler these training blocks should occur during the off-season. The amount of fatigue and muscle damage that occurs due to a concentrated block of high intensity eccentric training is detrimental to the bowler's performance during the in-season. The best timing during the off-season for these eccentric blocks are directly after a block of maximal strength and before the bowling loads of the bowler become too intensive. However, it is acknowledged that the effect of eccentrics can be mitigated with constant exposure to this type of training – repeated bout effect (Hosseinzadeh, Andersen, Arendt-Nielsen, & Madeleine, 2013). Therefore the strength and conditioning coach needs to be thoughtful as to when and where to use this type of training.

Power

Experts considered power training as very important but the least important strength quality. The reason being that fast bowlers cover a lot of this type of conditioning through simply bowling, and as stated earlier it is difficult to fit in and cover conditioning sessions for all strength qualities during a fast bowler's busy schedule. The strengthening of muscle for injury prevention and performance are higher on the priority list than the performance

benefits that are achieved through this type of conditioning. It is also understood that maintaining maximal strength can help to maintain power outputs (McMaster, Gill, Cronin, & McGuigan, 2013).

Two types of training are typically prescribed for power development. The first for the power training of fast bowlers is traditional Olympic power lifting (clean, power cleans, snatch etc). This type of training needs to occur with semi developed bowlers. These are the bowlers that have a good strength base from which they can build power. This style of training has been shown to increase performance in power athletes (Channell & Barfield, 2008). To increase bowling velocity bowlers need to transfer momentum that is initially generated via the lower body, transferred through the core, upper body and through to the ball at release point. It would seem logical that if the efficiency of this transfer of momentum is improved then the outcome or performance will be improved. This type of conditioning can help improve this. Furthermore, many of the Olympic lifts concentrate on driving the feet into the ground, which may have flow on effects to the delivery stride of bowling.

The second type of power training is plyometric conditioning. Again this has been proved to improve the performance of power athletes (Adriana, 2013) and will therefore be of benefit to fast bowlers. This type of training will not only help to improve the power output qualities of the fast bowlers but will also help to contribute to the jumping and landing mechanics of the bowler. These are very important aspects to a fast bowler considering that the delivery stride of the fast bowler involves jumping and single leg landing. Horizontal movements such as bounding and hurdling and landing exercises such as depth jumps are recognised as being very important for fast bowlers. Lateral exercises such as lateral strides, jumps, hops and step overs are less commonly associated with fast bowlers but are just as important due to the lateral aspects of fielding.

Either of these types of training can be performed as “top-up” training towards the end of the off-season, during the pre-season and potentially during the in-season, if athletes have power deficits or trouble retaining power capability. As suggested via Figure 1 this type of training should not be performed until other milestones have been achieved. It has been suggested that the amount of plyometric training performed during the in-season needs to be closely monitored due to the extra load and stress placed on the bowlers body in addition to the substantial bowling loads.

Aerobic

Fast bowling is generally thought of as a skill that is power/strength/speed based and endurance based. The strength and power aspects have been discussed previously. With regards to the aerobic needs, fast bowlers can cover around 22 km per day in a multi-day game, 16 km in a one dayer and 8 km in a T20 match (Petersen, Portus, et al., 2009; Petersen, Pyne, Dawson, et al., 2011; Petersen et al., 2010; Petersen, Pyne, Portus, et al., 2011; Petersen, Pyne, Portus, et al., 2009). Experts believed that aerobic fitness is very important to fast bowlers but it does have a variance of importance between formats with it logically being more important as the format duration increases. Endurance can be conditioned in conjunction with many other conditioning qualities and also helps to improve other conditioning qualities such as anaerobic fitness levels (Raoa, Johnsonb, & Chittibabu, 2013).

Regardless of development level bowlers should have a concentration on this area throughout their careers. Depending on the format focus the bowler's goals should be to progressively build the distance that they cover until they achieve distances that they would be required to cover in a game. This can be achieved in many different ways and it is important to note that during a game not all this distance is covered by running, not all this distance is covered in one session and the bowler is not required to cover this distance every day. It is only covered on bowling day. Therefore the distance/workload that the bowler covers in a training day needs to be prescribed and monitored. Some of this total distance or aerobic conditioning can be covered through running, some through walking (shopping, golf etc) and some through performing their anaerobic and speed conditioning. It also needs to be periodised so that they are having rest and recovery days in order for adaption to occur.

Once this distance has been progressively built it needs to be maintained. Therefore as the bowler get closer to the season and bowling loads increase, the amount of aerobic conditioning decreases. The same total distance is being covered but more of that distance is being covered via other training e.g. the increased distance covered in skills sessions (bowling run-up, fielding, etc.) and the distance covered via the increase in anaerobic and speed sessions.

Experts suggested that only one session of high intensity conditioning needed to occur every 10 days in order to maintain aerobic fitness levels. It was also suggested that these

conditioning requirements can be covered via the distance covered playing the game. This distance again needs to be closely monitored and programmed with an understanding of the upcoming schedule. If a bowler is in the middle of a T20 series but there is an upcoming test match series, then extra distance or conditioning will need to be programmed on top of the game demands on specific days and in conjunction with bowling loads. If the bowler is in the middle of a test series with a T20 series approaching then most or all of this conditioning should be covered by game demands.

Anaerobic

Anaerobic fitness was rated by the experts as the second most important fitness quality to train and maintain. It was acknowledged that run-up speed is an important determinant of ball release speed and therefore bowling performance (Duffield et al., 2009; Glazier et al., 2000). Fast bowlers can bowl up to and potentially above 50 overs (300 deliveries) in a test, which involves 300 sprints during a game. The performance of each of those individual sprints are critical to the performance of each delivery. Hence repeated sprint ability or anaerobic capacity of the fast bowler is critical.

It is suggested that the anaerobic conditioning block should be mainly periodised following a traditional sequential periodization model, with aerobic conditioning at the start of the off-season, followed by anaerobic and then speed conditioning as the in-season nears. However, the periodization differs slightly to the traditional model, in that anaerobic conditioning is part of a total load or distance that needs to be covered by the bowler as explained previously. As the bowler nears the in-season, the amount of distance covered anaerobically should be built alongside the sequential increase in total distance covered. The percentage of the distance covered through anaerobic conditioning of the total load should also increase as the in-season gets closer. Simply stated as the season nears, higher intensity anaerobic conditioning is increased whilst reducing the emphasis on aerobic conditioning.

Anaerobic conditioning is also similar to aerobic conditioning in that the experts suggested that the bowler only needs one high intensity session every ten days to maintain anaerobic fitness levels during the in-season. The distance covered during the game needs to be monitored as the requirements needed to maintain this level of fitness can easily be covered

in a game, therefore freeing any time that is available between games for conditioning qualities that cannot be covered off in game e.g. strength.

Speed

Speed was rated by the experts as significantly important, thus highlighting a fast bowler needs to be a fully rounded athlete. As stated in the previous section the maximum speed of the fast bowler is critical to the performance of bowling (Glazier et al., 2000). Furthermore speed is important in other aspects of the game that bowlers are still involved in e.g. running between the wickets and fielding.

In developing bowlers this should be something that should demand a large amount of attention and time. Efficient running technique is essential not only for performance but injury prevention also (Exell, Gittoes, Irwin, & Kerwin, 2012). Given that it takes a significant amount of time for an athlete to master a skill (Jacobs, 2009), the earlier that a fast bowler can optimise their sprinting technique, theoretically better the performance benefits and reduced likelihood of injury. For these reasons speed should be a focus through the fast bowler's entire programme but should generally follow a traditional sequential periodization model with a higher concentration of speed training as the in-season approaches.

Developed bowlers who have maximised their speed ability need to maintain this quality. The experts have suggested that only one high intensity session needs to occur every ten days during the in-season to maintain speed qualities. This can be covered in games and practices and therefore not needing any special attention outside of competition. However it is key to monitor the intensity of the sprints that occur during the game. At upmost best bowlers hit a peak of 90% of their maximal speed during their bowling run-up (Duffield et al., 2009) and it is understood that athletes need to train at close to maximal speed in order to improve and maintain speed (Grewcock, 2003). If the bowler is not reaching close to their maximum speed through other aspects of the game (batting and fielding), then additional speed sessions will be required.

Conclusion

A systematic approach that is underpinned by achieving performance milestone is the hallmark of the proposed system for the physical preparation of the fast bowler for the demands of 1st class and international cricket. A long-term approach needs to be adopted where the length and focus of the program depends largely on three main factors. 1) The length of the individual's off-season compared to in-season as the off-season in general terms is where fast bowlers can make their greatest conditioning gains and the in-season is mainly about maintenance. 2) The development level of the bowler. The more developed the bowler is the older their training age and therefore (ideally) the better their conditioning level. Far more attention can be paid to maintenance of the general conditioning aspects and more attention paid to the specific needs of the bowler. 3) The musculo-skeletal maturity of the individual bowlers. Before this maturity occurs there needs to be a focus on preventing a bowler from being fully immersed in an international program that can run for 12 months. Multifactorial consideration needs to be given to the bowler's workload to prepare them for the demands of fast bowling and at the same time preventing injury.

In-season is an area where specific attention needs to occur in order to make sure that the bowlers maintain or if need be increase their conditioning levels. The conditioning qualities outlined in MC1 (Figure 1) are monitored outside of game time e.g. within the strength sessions, etc. The need to monitor the aerobic, anaerobic and speed aspects that occur in games and trainings is much harder but crucial. If the strength and conditioning coach understands the distance and intensity that each player has covered during games and trainings then they have a far better understanding of what potential top-up sessions need to occur. This level of diagnostics and subsequent prescription can be achieved via GPS analytics. For example, this technology will give insight as to how often during the week, within games and trainings, a bowler has achieved the intensity to maintain their speed and if a subsequent top up session is needed every 10 days.

Future research directions

Further investigation needs to examine the best form of periodization for the fast bowlers. A traditional linear progression seems logical for most areas of conditioning associated with fast bowlers but does not align with a progressive bowling loads programme where as the load increases so too does the intensity. As mentioned during this paper the load that the

bowler endures during the bowling programme needs to be incorporated as part of the total load of the entire conditioning programme. Therefore a linear periodization approach may not always be the best option.

The role that the core plays in the action of fast bowling in regards to injury prevention and performance enhancement needs to be better understood. Specifically what contribution does the core play with rotational power movements? What are the best field assessments and best practice for conditioning this area?

In general a more in-depth investigation is required around strength and how it relates to fast bowlers. Some questions that warrant further investigation include what type of strength is most beneficial (relative strength versus strength endurance etc.), what muscular actions to train and when (eccentric, concentric and isometric), how much strength is needed in the lower body relative to the specific demands of individual bowlers and do all of these factors vary with specific body types and bowling actions?

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