SCALING THE PITCH FOR JUNIOR CRICKETERS

by

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ABSTRACT

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Although cricket is played around the world by all ages, very little attention has been focused on junior cricket. The research presented here evaluated the effects on junior cricket of reducing the pitch length, developed a method for scaling the pitch to suit the players and applied this method to the under-11 age group. In the first of four studies it was established that shortening the cricket pitch had positive effects for bowlers, batters and fielders at both club and county standards, consequently resulting in matches that were more engaging. The second study found that top under-10 and under-11 seam bowlers released the ball on average 3.4° further below horizontal on a 16 yard pitch compared with a 19 yard pitch. This was closer to elite adult pace bowlers' release angles and should enable junior players to achieve greater success and develop more variety in their bowling. The third study calculated where a good length delivery should be pitched to under-10 and under-11 batters in order to provoke uncertainty, and also examined the influence of pitch length on batters' decisions to play front or back foot shots according to the length of the delivery. A shorter pitch should strengthen the coupling between the perception of delivery length and appropriate shot selection, and the increased task demand should lead to improved anticipation; both are key features of skilled batting. In the final study a method of calculating the optimal pitch length for an age group was developed which used age-specific bowling and batting inputs. This was applied to scale the pitch for under-11s giving a pitch length of 16.22 yards (14.83 m), 19% shorter than previously recommended for the age group by the England and Wales Cricket Board. Scaled in this way across the junior age groups, pitch lengths would fit the players better as they develop, enabling more consistent ball release by bowlers and temporal demands for batters, as well as greater involvement for fielders.

PUBLICATIONS

Published papers

Harwood, M. J., Yeadon, M. R., & King, M. A. (2018). Reducing the pitch length : Effects on junior cricket. *International Journal of Sports Science and Coaching*, *0*(0), 1–9. http://doi.org/10.1177/1747954118772482

Harwood, M. J., Yeadon, M. R., & King, M. A. (2018). Does shortening the pitch make junior cricketers bowl better? *Journal of Sports Sciences*, *36*(17), 1972–1978. http://doi.org/10.1080/02640414.2018.1428884

Conference proceedings

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Other publications

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DEDICATION

To my wife, Sue: to paraphrase Sir Steve Redgrave, “If you see me go near another PhD, you have my permission to shoot me”. Also to our daughters, Beth and Alice, especially for lending a hand (Figure 4.2).

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CHAPTER 1
INTRODUCTION

In many sports the rules and playing area dimensions were laid down long ago and have remained essentially unchanged. Cricket of a sort had been played for many years, possibly centuries, before the "Articles of Agreement by and between His Grace the Duke of Richmond and Mr Brodrick (for two Cricket Matches) concluded the Eleventh of July 1727" specified that the wickets should be pitched 23 yards apart (Major, 2007). Within twenty years however, the first version of the Laws of Cricket, the "Code of 1744", specified the standard length of the pitch to be the 22 yards or 20.12 m (one "chain", the width of a Saxon acre-strip) which still applies to the current day (Altham and Swanton, 1948; Booth, 2018). It is interesting to note that this distance was set in an era when bowling was (like lawn bowls) an underarm delivery where the ball was rolled; not until 1864 did the Laws of Cricket permit overarm bowling in the fashion used today (Major, 2007).

1.1 THE AREA OF STUDY

This research explores the potential of scaling the cricket pitch for junior cricket, focusing on players aged ten and eleven years old, typically the age group at which players begin to play "hardball" cricket (using traditional cricket balls and wooden bats). At the commencement of the project the national governing body, the England and Wales Cricket Board (ECB), were aware of the concern that, notwithstanding their junior pitch length recommendations in place at the time, junior cricket was being played on pitches that were disproportionately long for the size and developmental stage of the players. The recommendation in place for under-10 hardball cricket for example of 19 yards (17.37 m), was only three yards (14%) shorter than the standard pitch despite the huge difference in stature and physical ability between the age of ten and adulthood. There was a feeling that these pitch lengths hindered player development and enjoyment.

Particular areas of concern were that:

- young bowlers struggled to bowl the required distance, resulting in many balls released at or above the horizontal or that bounced more than once and/or passed wide of the batters;
- bowlers needed to alter their basic technique as they matured to suit the pitch length which, relative to their height, became shorter;
- batters played a limited range of shots, often inappropriate to the length of the deliveries, and weren't required to develop anticipation skills;
- wicket-keepers stopped many balls at ankle height and did not have the opportunity to catch the ball;
- the difficulties experienced by the bowlers meant that batters were too infrequently able to play scoring shots and when they did these were concentrated in a small area of the outfield, the result being extended periods of inactivity for some fielders.

However no research had been conducted to verify or refute these observations or beliefs. Furthermore a brief survey of junior leagues around England revealed that the existing pitch length recommendations are not always adopted, for example while most leagues stipulate the recommended 20 yard (18.29 m) pitch for under-11 hardball, a variety of other lengths were also noted. In a small number of cases junior teams are expected to play on a 22 yard wicket regardless of age, seemingly on the basis that "they'll have to get used to it". As a consequence this study was instigated by the ECB so that future revisions to the pitch length recommendations would have the backing of scientific research to strengthen their case for any changes.

Bowling is fundamental to the game, like the serve in tennis, and is an area where inadequacies are very exposed. In order to bowl a ball that will land "on a good length", the area where a batter is uncertain whether to play forward or backward, a bowler must release the ball with the right combination of speed, angle and height. Physical maturity will limit the speed and height at which the bowler can project the ball, while technique will determine how well the physical capabilities are utilised and the angle at which the ball is released.

If a shorter pitch enables better bowling, this will in turn require better batting and wicket-keeping skills, and if as a result batters play a greater range of shots, more fielders and fielding skills will be involved. Not only might techniques improve, but the overall success and enjoyment should be enhanced by a faster, more dynamic game.

Previously only one study has explicitly investigated the effect of pitch length on junior cricket. In that study Elliott, Plunkett and Alderson (2005) considered the implications of pitch length for bowler injury potential and accuracy, and recommended 18 m (19.7 yard) pitches for under-11 and under-13 players. Another study (Portus and Farrow, 2011) looked at batting skill acquisition and mentioned the potential for reducing pitch lengths in youth cricket to enhance the anticipation skills of batters. Recently Cricket Australia have revised their junior formats and included reduced pitch lengths for age groups younger than under-15s, although no research supporting these changes has been published.

In their discourse on making the sport fit the children Lee and Smith (2003) nicely expressed some of the potential and the challenges of the task ahead:

> In cricket the use of short pitches allows bowlers to be more accurate which itself benefits batsmen because the ball will arrive more often in the striking area. However, faster bowling will pose a further problem to batsmen because they will have less time to see the ball and respond so it is important to create a balance between the demands of batting and bowling. (p. 265)

Although ultimately the results from this research must be applicable to all standards of junior cricketers in the age group, it is important not to reduce the need for bowlers to develop a good technique by making it unduly easy for them. Basing any pitch length recommendations on the abilities of some of the best age group bowlers should encourage all bowlers to develop better technique. It is also important that the demands on batters and wicket-keepers shouldn’t be excessive, such that they have insufficient time to make and execute appropriate shot choices.

1.2 STATEMENT OF PURPOSE

This research seeks to evaluate the effects on junior cricket of playing on a shorter pitch and ultimately to determine the optimal pitch length for the under-11 age group. On this length of pitch a good under-10 or under-11 seam bowler should be able to bowl a good length delivery while releasing the ball with an initial trajectory like that of an elite seam bowler.

The first stage is to evaluate the effect that shortening the pitch has on matches. This will be followed by assessing the influence that the pitch length has on how bowlers project the ball and whether batting on a shorter pitch improves the coupling between the length of the delivery and the choice of front or back foot shots by batters. In the process of analysing shot selection in relation to the length of the delivery, an estimate of what constitutes a good length for the age group will be determined. Finally the bowling and batting data obtained will serve as inputs to a pitch length model in order to calculate the optimal pitch length for the age group

1.3 RESEARCH QUESTIONS

How does playing on a shorter pitch affect objective measures of performance in junior cricket matches?

It is hypothesized that bowling should be more accurate and of a better length (i.e. not Wide or bouncing twice or more before passing the stumps), therefore resulting in more attempted shots by the batters, although it is possible that more full toss No balls might be bowled. Shorter pitches should enable more running between the wickets but could restrict the opportunities for batters to score boundaries, particularly to the Mid-wicket area where most young players find it easiest to hit the ball. The combination of more shots, more running and fewer shots to Mid-wicket should lead to more frequent and more even involvement of fielders.

How do young bowlers bowl on the currently recommended pitch length?

Analysis of ball release speed and angle by good standard junior bowlers will reveal whether they do indeed release the ball at or close to horizontal as anecdotal evidence suggests, and provide a baseline bowling speed for comparison with a shorter pitch.

How does bowling on a shorter pitch length change how young bowlers bowl?

Analysing the bowlers when bowling on a shorter pitch will indicate how speed and angle of ball release are affected. The potential for pitch length manipulation to encourage young bowlers to release the ball more like mature, elite bowlers without detrimentally affecting their ball release speed will be assessed.

What is a good length for junior seam bowlers to bowl?

By analysing the front or back foot shot selection by top junior batters to balls of different lengths delivered by top bowlers of the same age group, a region which results in similar proportions of front and back foot shots will be determined. This constitutes the good length region for the age group as balls pitching here result in the greatest indecision in the minds of the batters (Bradman, 1958).

How does pitch length affect the batters' shot selection?

On the currently recommended pitch lengths it is felt that batters often choose to play forward to short deliveries contrary to the accepted method. This is particularly thought to be the case in club cricket where much of the bowling can be slow and tend to bounce more than once. It is hypothesized that better bowling on shorter pitches will encourage batters to choose whether to play front or back foot shots more appropriately, that is to say a delivery pitching shorter than a good length will be more likely to result in a back foot shot, and vice versa.

What is the optimal pitch length for the age group?

The data regarding typical ball release speed and position by good young bowlers and information from the literature regarding the typical ball projection angle by elite pace bowlers will enable ball flight from hand to pitch to be modelled. Combining ball release position in relation to the bowlers' end stumps, ball flight and the good length figure will enable the optimal pitch length for the age group to be determined.

1.4 Chapter Organization

Chapter 2 reviews the limited amount of literature on the subject of junior or youth cricket and goes on to discuss research into modified sport. Literature concerning response time and the potential for injury is then considered, as well as that related to the development of anticipatory skill by batters.

Chapters 3 to 6 are written in the form of journal articles, chapters 3 and 4 having already been published. As such a small amount of duplication has been unavoidable.

Chapter 3 describes a study of county under-10 and club under-11 cricket matches played on two pitch lengths in which the effects of the pitch length on a number of objective game measures was determined.

Chapter 4 reports a study of top junior under-10 and under-11 seam bowlers bowling on two pitch lengths examining the influence of the pitch length on the way in which the bowlers released the ball.

Chapter 5 examines the shot selection of top order batters playing against seam bowlers in county under-10 matches. Probit analysis is used to determine what constitutes the good length region. This is then used to examine whether batting on a shorter pitch increases the proportion of back foot shots played to short deliveries and front foot shots played to full deliveries in a series of club and county matches.

Chapter 6 describes a model of the pitch length which incorporates information about the ball release by the bowlers reported in Chapter 4 and the age-specific good length estimate calculated in Chapter 5 in order to determine an appropriately scaled pitch for the age group. The sensitivity of the pitch length calculation to bowler variability and also the effect of pitch length on outcomes for bowlers are explored.

Chapter 7 summarises the project and answers the research questions posed in section 1.3. Limitations of the research are discussed and possibilities for further research, including the potential application of methods of this kind to scaling the playing environment in other sports, are suggested.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter considers the existing research focused on junior cricket before looking at the topic of modifying sport for young players. The potential implications of reducing the dimensions of playing areas with particular reference to throwing, striking and catching sports are reviewed from the perspectives of player response times and the potential for injury, and also the development of anticipation skills by batters. As several subsequent chapters include review and discussion of the pertinent literature, where possible an attempt to avoid repetition has been made.

2.2 YOUTH OR JUNIOR CRICKET RESEARCH

Cricket is played around the world from a very young age, take for example All Stars Cricket in England (https://www.ecb.co.uk/play/all-stars) and Junior Blasters in Australia (https://playcricket.com.au/junior/cricketblast-juniorblasters) both aimed at introducing 5 to 8 year olds to the game. Despite this, cricket for children or younger adolescent players has received very little research attention. Even where cricket studies have had youth or junior participants, rarely are they much below 14 years of age, for example in Sarpeshkar, Mann, Spratford and Abernethy (2017) the "youth" cricketers were 16 to 23 years old and in McNamara, Gabbett, Naughton, Farhart and Chapman (2013) the "junior" cricketers averaged 17.7 years of age.

Much of the research mentioning young cricketers has related to injury incidence or risk, either general surveys of cricket-related injuries, for example Brukner, Gara and Fortington (2018) and McGrath and Finch (1996), or specifically looking at bowling where the key concerns are knee and lower back injuries. Often these have considered the (fast/pace) bowlers' "workload" in terms of bowling frequency and number of overs bowled in matches or practice (https://www.ecb.co.uk/news/79257; https://community.cricket.com.au/clubs/youth-pace-bowling-guidelines).

Dennis, Finch and Farhart (2005) monitored 40 male fast bowlers aged between 12 and 17 years over the course of a season and concluded that rest days between practices or matches should be added to bowling workload guidelines for fast bowlers, alongside the total number of overs and days per week young fast bowlers should be allowed to bowl. Davies, du Randt, Venter and Stretch (2008) studied 11 to 18 year old fast bowlers and found that fitness, technique and workload in combination (but not clearly independently) influenced the likelihood of injury. It has also been suggested that acute workload may be related to injury rather than just the longer-term "chronic" workload, Warren, Williams, McCaig and Trewartha (2018) for example finding that spikes in workload were associated with adolescent fast bowler injuries.

Where young bowlers are studied, their age should be considered when setting the task or evaluating the results. An example of where this did not occur can be found in the recent study by Schaefer, O'Dwyer, Ferdinands and Edwards (2018) who looked at the influence of a prolonged spell of bowling (10 overs) on bowler kinematics and kinetics. Despite the players studied ranging from 12 to 19 years of age, all bowled on a standard 22 yard pitch, trying to bounce the ball in the same area and no account was taken of the workloads relative to age-related recommendations. Consequently the youngest bowlers bowled 250% of their recommended spell duration, while the oldest bowlers only bowled 25% more. The study concluded that adhering to the bowling spell limits could not be justified on the basis of changes to technique or load-related risks because they found no significant changes in measures of these factors. However a comparison of the effects on the oldest and youngest bowlers over the course of the spell might have revealed something entirely different from the changes to the mean data, especially as the younger participants were bowling on a full length pitch.

Pardiwala, Rao and Varshney (2018) quote lumbar stress fractures to young fast bowlers as the most severe modern-day cricket injury. Gregory, Batt and Wallace (2002) surveyed the injuries to young pace *and* spin bowlers (between 9 and 21 years of age) and although pace bowlers were two and a half times more likely to report an injury (0.165 per thousand deliveries for pace compared with 0.066 per thousand deliveries for spin), this was not found to be a significant difference. Interestingly they found the rate of lower back injuries not to be significantly different between the styles of bowling.

Elliott (2000) discussed front-on, side-on and mixed fast bowling actions, and concluded that shoulder counter-rotation should be limited in order to prevent low back injuries. Subsequently, in the only study explicitly exploring the effects of cricket pitch length on youth cricket, Elliott, Plunkett and Alderson (2005) investigated the bowling performance and technique of fourteen under-11, eleven under-13 and twelve under-15 fast bowlers on three pitch lengths. Analysis of the fastest of three recorded deliveries by each bowler on 16 m (17.5 yards), 18 m (19.7 yards) and 20.12 m (22 yard) pitches showed that while mean bowling speed was unchanged, mean accuracy tended to reduce as the pitch length increased for all age groups. Shoulder counter-rotation increased most noticeably for under-11 and under-13 bowlers between the 18 m and 20.12 m pitches, while counter-rotation by the under-15 bowlers did not change appreciably across the different pitch lengths, possibly because technique is more established by that age. On the basis of these results they suggested that under-15 bowlers should continue to play on standard 20.12 m pitches, while younger players should play on 18 m pitches. However while this study provides some evidence that reducing the pitch length should be beneficial to young bowlers, a more extensive investigation would be warranted before playing recommendations should be altered.

Recently a systematic review of studies concerned with non-contact injuries to adolescent pace bowlers (Forrest, Hebert, Scott, Brini and Dempsey, 2017) cast some doubt on the role of mixed actions, shoulder counter-rotation and bowler workload on injury potential. The survey pointed towards “excessive lateral trunk flexion while bowling, pelvis and hip bowling kinematics, reduced trunk extensor endurance, and poor lumbo-pelvic-hip movement control” instead.

Although there tends to be a focus on the knee or lower back injuries to bowlers, Nag, Murugappan, Chandran, Mohan and Das (2009) highlighted a case of “little leaguers’ elbow” (an overuse injury to the medial epicondyle of the elbow commonly seen in young baseball pitchers) in a 12 year old pace bowler. They pointed out that injuries of this sort to junior cricketers may come as a result of striving for speed and supported the need for bowling workload restrictions. Although bowlers seek to bowl quickly, part of the need to bowl faster may come from playing on pitches which are too long for them. Shortening the pitch would reduce the effort required to get the ball to the batter and should enable increased control, together these should reduce the stress at the elbow.

Studies of cricket batting involving young cricketers have primarily concerned the attainment of expertise and are discussed in the sections which follow.

2.3 MODIFIED SPORTS

Many sports, including cricket, have smaller playing equipment (e.g. bats, rackets, balls) available to suit young players and some, such as tennis, baseball and basketball have adapted aspects of the playing environment to enhance the experience for young players: tennis by reducing the court dimensions and net height (e.g. http://www.tennisplayandstay.com/tennis10s/overview.aspx); baseball by reducing the pitching distance, diamond size and distance to the fence (e.g. https://www.littleleague.org/league-officials/field-specifications; http://www.pony.org/Default.aspx?tabid=899396); basketball by lowering the basket and reducing court dimensions (e.g. http://www.fiba.com/documents). However Buszard, Reid, Masters and Farrow (2016) noted that most sports they surveyed adopted adult-sized courts, fields, etc. by the age of 10 to 12, the exception being soccer.

Winter (1983) reviewed the problems for children playing “adult sports” and the benefits of modifications, with particular reference to the situation existing in Australia at the time. She also surveyed the modifications in use for under-12 year olds across a range of sports. She made the point that modified sports should retain the same basic intent of the adult version and that carefully developed modifications should enable a smooth transition to the adult game.

Five areas of potential modification were identified:

a. Size of playing area and playing time;
b. Team size;
c. Equipment used;
d. Rules, particularly technical rules which may limit freedom of play or be difficult for players to understand;
e. Organizing players by height and weight rather than age.

McCarthy, Bergholz and Bartlett (2016) listed five very similar "domains" for their principles of Sport System Re-Design, namely: playing space, equipment, rules of the game, rules of the league and roles of individuals (e.g. players, coaches, referees/umpires).

Taking Winter's list, most of these aspects are currently adapted in junior cricket. Playing time and team size are reduced (fewer overs and often 8 players-a-side), smaller bats and slightly smaller balls are used, and rule modifications are in place (e.g. the LBW law is often dispensed with or applied leniently, and No balls and Wides are rarely re-bowled but carry an increased run penalty). However age groups are still the norm and while ability rather than size banding might be worth considering, good bowlers aren't necessarily (and at older ages perhaps often) good batters, so that type of re-organization is problematic. There are existing guidelines regarding reducing the playing area, both in terms of boundary sizes and pitch length, but it isn't clear how these were arrived at.

The term "Competitive Engineering" has been coined by Damon Burton to describe an approach to youth sport modification designed "to enhance the competitive experiences of young athletes" (Burton, Gillham and Hammermeister, 2011, p.202). They suggested that modifications with the aim of increasing action and participation, keeping scores close, and creating positive social relationships will enhance development, learning and the desire to continue playing. Again modifying the dimensions of the playing facilities (for example pitch length/width, goal sizes or basket heights) was suggested as a key part of the process of maximizing action and scoring, as well as facilitating skill development:

> Using facilities and equipment that are developmentally-appropriate for the age, size and ability of the athlete should ensure that young performers develop sound fundamental skills rather than picking up bad habits while performing with adult-sized equipment or facilities. (Burton, Gillham, et al., 2011, p. 213).

Many other researchers have championed the need for scaled playing areas and equipment, but have also identified the absence of empirical research to underpin the precise changes to dimensions, for example Buszard, Farrow, Reid and Masters (2014a), Kachel, Buszard and Reid (2015), Larson and Guggenheimer (2013), Limpens, Buszard, Shoemaker, Savelsbergh and Reid (2018), Mann, Abernethy, Farrow, Davis and Spratford (2010), Reid, Buszard and Farrow (2018), Timmerman et al. (2015) and Winter (1983).

Buszard et al. (2016) conducted a systematic review of the literature relating to equipment and play area scaling in children's sport and concluded that, despite limited numbers of studies and some methodological shortcomings, the consensus favoured modified sport as a means to "enhance skill performance and … aid learning" (p. 829). Larson and Guggenheimer (2013) commented that the frustration of playing in inappropriate conditions (court size and ball bounce in the case of tennis) could lead to children avoiding the sport altogether. In a good example of the potential for simple modifications to counter this, Burton, O'Connell, Gillham and Hammermeister (2011) found that flag-football player attrition dropped from nearly 40% to less than 20% following a season where the ball size was reduced and a "delayed-rush" rule was introduced, no doubt helped by a more than 100% increase in scoring and a 75% increase in the number of players scoring touchdowns. Similarly Morley et al. (2016) found that modifying under-7 to under-9 rugby league (primarily fewer players, smaller pitch and touch tackling) increased the number of passes, catches, plays and tackles and led to more scoring, the combination of which they believed would improve player retention in the sport. Although Talpey, Croucher, Mustafa and Finch (2017) were not concerned with modified formats of the game, they found that the retention of junior cricketers from one year to the next was significantly influenced by the players' engagement in matches and their ability to express their skills (for example by scoring runs and taking wickets), all of which modified sports seek to encourage.

Arias, Argudo and Alonso (2009) found that simply reducing the area delineated by the 3-point line on the basketball court increased player involvement, shooting and shot success, although their modification was somewhat arbitrary (using the free-throw lane as the 3-point boundary) and probably not optimized to the players. Arias (2012) commented on the need for young players to achieve high accuracy and efficacy scores when shooting in basketball as it is a skill from which players derive great pleasure. It is also, like bowling in cricket, a skill in which inadequacies are very exposed. A high success rate is also a factor in implicit motor learning which is beneficial to children and which scaling is thought to encourage (Buszard, Farrow, Reid and Masters, 2014b).

It is worth making a distinction between “scaled” and just “smaller”. For example (field) hockey, association football and to some degree tennis junior age groups play on pitches/courts which fit conveniently on the existing standard (adult) ones, by turning the width of the standard pitch into the length of the junior pitch (England Hockey, 2015; ITF, 2011; The Football Association, 2012). Often there is a limited attempt at best actively to *scale* the playing area on the basis of some parameter of the performance or performers. Height is most often alluded to even if not explicitly used, Chase, Ewing, Lirgg and George (1994) for example said “Equipment modification for smaller and younger players should equate the sport's parameters in proportion to the size of the players.” (p. 159), however Buszard et al. (2016) pointed out that height is not the only consideration when seeking an appropriate scaling ratio.

Smaller tennis courts for young players up to the age of ten have been introduced by several of the sport’s governing bodies, for example the ITF’s “Tennis 10s” (ITF, n.d.) and the LTA’s “Ariel Mini Tennis” (Procter, 2007). While the recommended court sizes and net heights pay some attention to the relative stature of young players, there is still a strong element of “convenience”, enabling the mini courts to utilize existing line markings. Bayer, Ebert and Leser (2017) asserted that the “smaller courts are scaled to the size of children” (p. 35) and yet their table showed that in only one of four age groups were the length and width of the court scaled from the standard court in a similar ratio to the relative mean statures of the children to adults. Furthermore, from around the age of eleven players are expected to move directly to a standard sized court, leading Martens and De Vylder (2007) to observe that “It generally takes 2 to 3 years of play on [the standard] court before the total tennis game that players could implement on the [under-10s] court becomes feasible again.” (p. 4). Tennant (2011) on the other hand has claimed that the performance decrement due to the jump to the full size court after the age of ten lasts typically three to six months, although this seems unlikely purely based on the size of the players and may be the result of players making adjustments to cope with the jump in court size. Indeed comparing the various Tennis 10s modifications with adult tennis Schmidhofer, Leser and Ebert (2014) found that the under-9s game resembled the adult game far more closely than the under-12s and especially the under-10s. The lack of a smooth transition to the adult game that effective scaling should enable led the Austrian Tennis Federation to introduce a further stage in the modified tennis structure in 2012 (Bayer et al., 2017). However, this scaled the court length and width to 87% of the standard sized court even though the age group targeted were only 75-80% adult stature, and still expected players to move to the standard court by the age of 12 at the latest (when their mean stature is still only around 80% of the mean adult).

Net heights recommended in Tennis 10s vary between 60% and 66% of the mean stature for the age groups, while the standard net is 54% of mean adult stature, or 50% of the mean of the top 10 elite men and women (Limpens et al., 2018). This study exploring the influence of tennis net height by Limpens et al. (2018) illustrates a difficulty associated with research looking at scaling ratios for children. The study was played on a standard sized court using four net heights, 40%, 50%, 60% and 70% of average 10-year-old stature, and 16 highly skilled 10-year-old players took part. They concluded that the recommended net height for the age group should be 0.65 m, 50% of average stature for the age (and similar to the height of a standard net in proportion to elite adult stature). However the players in the study had a mean height of approximately 90th centile for their age and they had been playing with a standard height net for 18 months before the study which will have influenced their results. The height of the players in the study also suggests that the existing tennis constraints result in a form of "sporting natural selection" on the basis of height from an early age and, given that a tall 10-year-old may become no more than an average height adult, this may limit the pool of tennis players staying in the game.

Alongside changing the size of the playing area and net height, tennis is often now played with slower and lower bouncing (low compression) balls for children (Newman, 2010) in order to encourage more comfortable hitting and a reduced temporal demand for the players, leading to better tactical play (Martens and De Vylder, 2007). The lower bounce leads to less extreme grips (since players aren't having to cope with very high bounce for example) and the development of a more all round game (McEnroe, 2010). Farrow and Reid (2010) looked at young players' (8.0 ± 0.4 years) playing on a standard and smaller court with standard and low compression balls and found fewer hitting opportunities and lower engagement when playing under the standard (adult) conditions. They also found that the court adaptation had a bigger positive influence than the ball change, but acknowledged that five 30 minute practice sessions over a period of five weeks may have been insufficient for the players to adapt fully to the constraints. Kachel et al. (2015) looked exclusively at the influence of ball compression when ten year olds played on a standard court and while many match characteristics were unchanged, lower compression balls led to slower rallies, more net play and an increase in balls played at a "comfortable height". These changes were interpreted as being beneficial to the development of an all-round game by young players.

Satern, Messier and Keller-McNulty (1989) and Chase et al. (1994) also found ball size and mass changes to have less influence than basket height on basketball free throws, although the modifications were not *scaled* to suit the participants and all shots in each study were taken from the same distance from the basket (15 feet/4.6 m or 12 feet/3.66 m respectively). By contrast Arias (2012) found that reducing the ball mass (while size and bounce were fixed) improved both shot accuracy and efficacy for 9 to 11 year old players' during matches. Satern et al. (1989) suggested that by 13 years (the age of their players), movements may be too well established to be affected by changes during their study, which may also reinforce the idea that scaled environments should be introduced from an early age and adjusted progressively to avoid the formation of bad habits (see also Burton, Gillham, et al. (2011) above). Arias-Estero, Argudo and Alonso (2018) and Arias, Argudo and Alonso (2012a, 2012b) found that reducing the mass of the basketball increased the number of one-on-one situations and improved dribbling, passing, pass-reception and decision-making.

It can be seen that one modification can have multiple effects upon the activity and while sometimes they may all be positive, that may not always be the case. Furthermore determining the degree of modification required to elicit a desired change, for example to make junior sport more closely resemble the adult version, can be difficult. Although studying stair climbing, Konczak, Meeuwsen and Cress (1992) identified that "Action capabilities are not exclusively defined by anthropometrics" and that "Most locomotor and upper-extremity tasks are subject to additional biomechanical constraints" (p. 691), for example muscle force, range of motion and coordination. The principle is likely to be true in sport, for example bowling, throwing, basketball and netball shooting, where "functional similarity" between age groups should perhaps be the goal of efforts to scale the environment. As Gagen, Haywood and Spaner (2005) noted, "complex tasks, which require multiple dimensions such as size and strength, are more difficult to scale to a single parameter" (p. 191).

Texier, Cohen, Dupeux, Quéré and Clanet (2014) suggested that playing field (or court, etc.) dimensions may have been at least influenced by the projectile range of the object thrown or struck (ball, shuttlecock, etc.) in the game. For example, there would be no sense in badminton courts being much longer than players can actually hit the shuttlecock as it would never "go long", or so short that it would too frequently fall out. They found a strong correlation between the length of the field and the predicted maximum projectile distance in the sport, with the ratio of the two being close to one for most of the sports they analysed. In addition to this characteristic distance in a sport, they also proposed a characteristic time, the ratio of the length of the field to the maximum projection speed. Sports where both the characteristic distance and characteristic time were close to or exceeded 1 they categorized as "target" sports (e.g. golf, association football and basketball). Where these ratios were both around or less than 0.5 the sports were categorized as "precision and reflex" sports (e.g. volleyball, tennis and table tennis). Of the sports they categorized, only badminton with a distance ratio close to one and a time ratio around 0.2 fell outside one of these two categories, but air resistance is much more influential in badminton than in most sports.

Texier et al. (2014) neglected to comment on the fact that for some sports (baseball, softball and cricket most obviously), there is more than one characteristic range in the sport: they discussed the playing field size (boundary) based on bat exit velocity, but there is also the pitcher/bowler to batter distance, which should be based on pitching or bowling speed. Using maximum bat exit velocity and the field size classified baseball and softball as a target sports, using pitching distance and speed would, perhaps more appropriately, put baseball and softball in their "precision and reflex" category. This method could be considered as a way of optimising boundary distances for junior cricket, such that the typical throwing and "six-hitting" distances of an age group could be used for guidance, and the pitch length could be scaled based on the range of the ball bowled in a functionally similar way to adults.

Timmerman et al. (2015) in essence used a similar idea to Texier et al. (2014)'s characteristic time by scaling both the tennis court and net height in an effort to make the temporal demands (based on ball racket to racket time) of junior play closer to that of elite adults. They found that scaling the net was particularly important for both performance and enjoyment. Their scaling ratio however still meant that the average racket to racket time in junior matches with a scaled net and court was 25% longer than that of the adults, so perhaps their scaling ratio of 0.76 should have been reduced further. On the other hand Larson and Guggenheimer (2013) suggested that the speed of the game should be slowed down to match the capabilities of the children, not increased to mimic adults (even if only in relative terms). However they studied 7-9 year olds while Timmerman et al. (2015)'s players were 9.7 ± 0.5 years and elite age group players.

It is clear that stature is only one means of scaling the playing environment, and a fairly basic one at that. In some sports several aspects could be candidates to be scaled (e.g. court size and net height) and it is possible that different scale factors should be employed for each. In baseball a characteristic time based on pitching speed might be appropriate for scaling the distance from pitching mound to home plate, but that would be unlikely to be an appropriate scale factor for base path distances, where typical running speed might be more suitable. It is also possible that more than one scale factor could suggest itself for the same environmental dimension, in which case focusing on a particular outcome (e.g. enabling young bowlers to bowl in a functionally similar way to adults) or attending to safety concerns (e.g. ensuring that batters have enough time to select and execute an appropriate shot) could determine which takes priority if they are found to be in conflict.

2.4 RESPONSE TIME AND INJURY POTENTIAL

Injury rates from ball impacts which result in junior cricketers being unable to play forthcoming matches are low (Finch, White, Dennis, Twomey and Hayen, 2010; Stretch, 1995, 2014; Walker, Carr, Chalmers and Wilson, 2010). Nevertheless shortening the cricket pitch would have the consequence of reducing the time available to batters to select and play a shot, or avoid the ball, and also the time available to the bowlers to catch or avoid the ball should a shot be played directly back towards them. According to the ECB Fielding Regulations (England and Wales Cricket Board, n.d.-a) fielders (except wicket-keepers and slip fielders) up to and including the under-13 age group are not allowed to stand within 10 m of the bat. Although close fielders should be more prepared to catch or avoid the ball than bowlers following through after release, even after several steps bowlers are still likely to be in excess of this when the ball would reach them.

A recent survey of cricket-related fatalities in Australia since 1858 by Brukner et al. (2018) revealed only one bowler fatality compared with 45 batters, and also showed that the rate of fatal injury had declined rapidly since the widespread use of helmets by batter, wicket-keepers and other close fielders. Compulsory helmet wearing has also been credited with the dramatic drop in head, neck and facial injuries among junior and professional batters over two to three years following the introduction of the regulation (Pardiwala et al., 2018; Shaw and Finch, 2008).

Concern in baseball and softball over catastrophic and fatal injuries to pitchers, particularly in response to improvements in bat performance, however has led to several studies of pitcher response time and the results from them can equally be applied to cricket batters and bowlers. McDowell and Ciocco (2005) estimated that softball and baseball pitchers have a minimum of approximately 420 ms based on typical batter-to-pitcher distances and the maximum batted ball speeds recommended by the United States Speciality Sports Association, the Amateur Softball Association and the National Collegiate Athletic Association. This is slightly longer than Cassidy and Burton's estimate (quoted in Nicholls, Miller and Elliott, 2005) that an adult pitcher needs 400 ms to evade or catch "line drives", a baseball driven back to the pitcher from home plate.

Owings, Lancianese, Lampe and Grabiner (2003) found that although their response accuracy wasn't high, even 8-9 year olds could respond quickly enough to balls projected at them from a ball machine at 26.8 $m.s^{-1}$ from a distance of 13.7 m, however trying to "shadow catch" a baseball while protected by a net probably does not encourage participants to try their hardest. This is faster than typical under-11 cricket bowling speeds of 20 to 24 $m.s^{-1}$ (Elliott et al. (2005) and Chapter 4), over a shorter distance than a cricket pitch and it affords the receiver approximately 510 ms to respond (neglecting air resistance). Interestingly the catchers of all ages in their study responded more quickly to a more challenging condition where the balls were projected at 33.5 $m.s^{-1}$. Lipps, Eckner, Richardson and Ashton-Miller (2013) also confirmed that both men and women responded more quickly to more challenging situations, in their case a head protective response to foam tennis balls projected at 21 $m.s^{-1}$ towards the participants. Starting with a maximum distance from machine to participant of 8.25 m the demands of the task were increased by incrementally reducing the distance to an average minimum distance for men of 5.08 m and for women of 5.89 m. These studies suggest that increasing the task demand can actually improve the response time, though presumably only up to a certain level. Owings et al's calculations based on projection speeds of 33.5 $m.s^{-1}$ with participants standing

13.7 m away showed that responding to speeds in excess of 30 $m.s^{-1}$ should be manageable by most 8-9 year olds and the manageable speed was higher for older age groups. They found that deliberately dividing the participants' attention, to mimic game situations, reduced participants' performance at the higher speed by approximately 10%.

In a study more similar to the cricket bowling situation Matta, Myers and Sawicki (2015) assessed in a laboratory setting the ability of 9 to 13 year old baseball pitchers to avoid a ball projected from a ball machine simulating line drives. Their results showed that the probability of a pitcher being hit by (rather than catching or tipping) the ball was about one in three when the time to respond was approximately 500 ms. This was based on the first two attempts by the pitchers and therefore considered the worst case situation, but the study also showed that pitchers quickly learned to avoid or catch the ball, such that their chance of being hit after 6 exposures (with a random number of "no response needed" trials in between) had reduced by a factor of around four or five. However the machine used projected the balls at only 14.6 $m.s^{-1}$ with the distance from pitcher being adjusted to alter the time available to respond rather than the speed. This meant that the ball speed was unrealistically low but the transit distances for the balls were unrealistically short (at around 6 m compared with an under-12 Little League pitching distance of 14 m). Furthermore, as the authors acknowledged, the balls themselves were smaller than a baseball which will have increased the task difficulty for the pitchers.

Studies using machines to project balls at participants prevent their use of anticipation skills and situational knowledge, for example Pinder, Davids, Renshaw and Araújo (2011), Shim, Carlton, Chow and Chae (2005) and Young, Trachtman, Scher and Schmidt (2006), so probably overestimate the task demand in some respects, but some studies also make it easier by being predictable, involving fewer distractions, removing some of the randomness or making it easy to tell when the task will be harder, for example standing closer to the ball machine (Lipps et al., 2013; Matta et al., 2015).

Peploe (2016) looked at elite or near elite cricket batters range hitting, straight back over the bowler aiming for a "straight six", and found a maximum bat exit velocity of 39.6 $m.s^{-1}$ and a maximum range of 106 m, far in excess of the capabilities of young batters. In the worst case (again neglecting air resistance) this would give the bowler around 400 ms assuming the ball had to travel 15 to 16 m from the bat before reaching the bowler (assuming that the bowler has followed through towards the batter by about 1.5 m after release by the time the ball has been struck back), very similar to the minimum response times required for pitchers discussed for baseball and softball. In the absence of similar data for junior batters it is reasonable to assume that the time available to junior bowlers faced with a ball struck back at them by a batter in their age group is likely to afford them sufficient time to avoid or catch the ball.

2.5 BATTING ANTICIPATION AND LEARNING

Whilst it seems clear from the previous section that safety is unlikely to be a major concern for batters or bowlers, scaling down the playing environment from the standard size on the basis of one parameter or a combination of parameters, such as height, speed or time available, ignores the question of the capability of the players to be successful under the new conditions. In some sports, for example tennis, basketball and association football, all players are affected in a similar way by reductions in the pitch or court dimensions, but in sports like cricket and baseball something which facilitates improved bowling/pitching, could be detrimental to the batter (or wicket-keeper/catcher), therefore a degree of compromise may be necessary.

The first decision a cricket batter must make to each delivery is whether to play a front foot or back foot shot (McLeod, 1987) which depends upon how far away from the batter the ball is going to bounce (Bradman, 1958; Woolmer, Noakes and Moffett, 2008). Against all but the fastest adult pace bowling batters have somewhere just in excess of 500 ms from ball release until it arrives at their bat (Justham, West, Harland and Cork, 2006; McLeod, 1987; Sarpeshkar et al., 2017). Despite the limited time available to choose and execute a shot Müller and Abernethy (2012) pointed out that expert batters did this with considerable and reasonably consistent success. From their review they identified three sources of information which aided a batter's decision-making: prior expectations or situational probabilities; pre-delivery kinematic information from the bowler; and observation of the early flight.

2.5.1 SITUATIONAL PROBABILITY

Employing a temporal visual occlusion methodology during actual play Abernethy, Gill, Parks and Packer (2001) found that experts were able to predict squash shot direction and depth at better than chance levels even when occlusion occurred before any useable pre-delivery information was available (as much as 620 ms before racket-ball contact). They suggested that experts can draw on their knowledge of typical shot distributions, for example the much higher proportion of squash shots driven deep to the back court rather than drop shots, and familiarity with their opponents to assist their decision-making before the shot is played.

Similarly Shim et al. (2005) and Triolet, Benguigui, Le Runigo and Williams (2013) both found that expert tennis players' made early anticipatory movements based on tactical considerations only when they were placed in difficult situations or under time pressure, but suggested that they would rely on responding to early ball flight if they perceived that they had sufficient time. In a somewhat similar way, James and Bradley (2004) suggested that more pressure placed on an opponent restricted the shots available to them and therefore increased the situational information available to aid the receiver's anticipation. This type of response suggests that the players must possess a level of tactical awareness, but when comparing less-skilled and expert tennis players presented with both real video of their opponent and a novel abstract animation which removed postural information Murphy et al. (2016) found that even the less-skilled were able to use purely contextual information to assist their decisions regarding ball direction and depth, though not as well as experts. They did however find that judgement of the depth of the ball (similar to the length of a cricket delivery) was more dependent upon postural information than was judging the direction. Their participants though were all adult (mean age 24 years) and even the less-skilled group had a mean of seven years' tennis experience and played for more than an hour per week. Of course in games such as tennis, badminton and squash the width of the court and relative positions of the two players will make anticipating the likely direction of the shot easier than the very narrow angles and relatively fixed positions of batter and bowler in cricket.

Paull and Glencross (1997) studied expert and novice baseball batters and found that both were able to use situational probabilities to improve their batting performance. All participants were again adults (and unusually the novices, mean age 29 years, were older than the experts, mean age 23 years) and while the novices lacked the playing experience of the experts, their knowledge of the game structure (in which situational probabilities are fundamental to the rules) may have been comparable.

Farrow and Reid (2012) looked at skilled tennis players of two different ages anticipating serve direction during a series of games. Game score information was available and the serve on the first point of each game was directed to the same place, while all other serves were to randomised locations. Older players (average age 17.9 years) were able to detect the pattern while the younger players (11.3 years old) were not. They suggested that younger players do not have the need to anticipate because the temporal demands are not high at their level and possibly because their opponents do not have the tactical plans for them to anticipate. Cañal-Bruland and Mann (2015) also emphasized the increased importance of contextual information as the temporal demand for the "receiving" player goes up, either due to the approaching projectile's speed or the reduced distance separating the two players. It is easy to see parallels in junior cricket where on current pitch lengths and at the speeds at which young players bowl, batters are unlikely to need to rely on match context, fielder placement or anticipating a bowler's plan (if it exists) to improve their ability to select their shots.

One aspect of situational probability which seems common to the shot selection of both adult and junior cricketers is the bias towards a front foot shot. Abernethy and Russell (1984) for example noted what they termed the "general purpose" front foot defensive response made by batters when they are uncertain about the length of the delivery. Likewise Penrose and Roach (1995) noted that batters could "tend towards an incorrect 'default' prediction made well in advance regardless of the delivery itself" (p. 210).

McLeod (1987) asked novice and expert batters to predict the length of deliveries (from a choice between "short", "good length" or "overpitched") when shown film of a bowling a series of balls which was occluded either at 0, 80, 160 or 240 ms after ball release. He highlighted the unusually high proportion of correct decisions made by expert batters when the ball was of "good length" (83% compared with 33% expected by chance alone) and even the novices (at 54% correct) outperformed chance. Interestingly the experts' success rate for good length balls reduced to 66% when they were shown the first 80 ms of ball flight which suggests that with no flight information they presume a good length or full ball, but once they have more information they attempt to make a decision. However McLeod's data must be considered with some caution as it would appear from close inspection that each participant (3 experts and 22 non-experts) viewed only six deliveries (one of each category), meaning that each expert response constituted 16.66% of the total.

Müller, Abernethy and Farrow (2006) conducted a series of studies using a variety of temporal and spatial occlusion conditions with highly skilled, intermediate and low-skilled adults batters trying to predict ball type and length (from a mixture of inswing, outswing and short balls by a swing bowler, and leg-spin, "wrong-un" (Googly) and short balls from a leg-spin bowler). They found some evidence that batters of all skill levels assumed that the ball would be full (which would ordinarily lead to a front foot shot) unless they had clear evidence to the contrary. A similar study by Müller and Abernethy (2006) used liquid crystal occlusion glasses to examine the ability of high- and low-skilled batters to use pre-release, pre-bounce and post-bounce information to play against three leg-spin bowlers. The bowlers bowled a mixture of full and short length leg-spin balls, and full length "wrong-uns", while the batters had to predict the ball length and type by playing actual shots. Even though the highly skilled batters were superior to low-skilled batters in their judgement of length, batters in both skill groups predominantly anticipated a full delivery when occlusion occurred at ball release.

Given that spin bowlers rarely bowl short, certainly at less than the rate of over one ball in three as in Müller and Abernethy (2006)'s study, a front foot bias is perhaps to be expected more than for faster bowling where the short delivery is used more frequently. Batters may come to expect full deliveries based on their higher frequency, in a similar way to Loffing, Stern and Hagemann (2015)'s finding that participants in a volleyball study, skilled ones in particular, tended to expect a pattern of attack to continue despite the kinematic information available to them (perhaps also akin to a batter being deceived by a fast bowler's "slower ball"). In junior cricket players may favour the front foot shot because it is the shot that they practice most and are coached to play from an early stage (Pinder, Davids and Renshaw, 2012), and also because young bowlers are predominantly coached to bowl good length or full balls.

Although the receiver/batter's anticipation has been the focus of research to date in this area, it is also possible for bowlers to anticipate a batter's intended shot on the basis of the situational probability (e.g. fielder placement, shot preferences, game situation) and thereby to bowl an unexpected ball. Again it is reasonable to assume that this level of awareness develops with experience and usually therefore age, hand-in-hand with the batter's increased abilities.

2.5.2 PRE-DELIVERY KINEMATICS AND EARLY FLIGHT

Mann, Williams, Ward and Janelle (2007) conducted a meta-analysis of research into perceptual-cognitive skill in sport looking for expert-novice differences. Their results were "consistent with the notion that the use of advance perceptual cues has been demonstrated to facilitate sport performance by means of aiding in the anticipation of opponent's actions and decreasing overall response time" (p. 472). Penrose and Roach (1995) suggested that the likelihood of cricket batters progressing to expert level is enhanced by learning to use advanced cues from pre-delivery movements. This was supported by Renshaw et al. (2007) who stated that "A key feature of expertise in cricket batting is learning to identify the specifying information from the body action movements of the bowler" (p.166) and Portus and Farrow (2011) who stated that "batsmen utilise advanced information in the form of movement kinematics emanating from the bowler's action (viz. bowling hand and arm) to anticipate the upcoming delivery and to allow them to begin their movement preparation." (p. 298).

Visual occlusion studies, predominantly with adults, have shown that the less skilled rely more on observing the flight of the ball (or shuttlecock) in order to decide upon their response, while experts have made their gross movement decisions (e.g. to play forward or back) on the basis of pre-release information and can use flight information for fine-tuning (Abernethy and Russell, 1984; Müller and Abernethy, 2012). Abernethy and Russell (1987) found that expert badminton players were better than novices at picking up and using earlier cues from their opponents. However there may be more obvious pre-flight information available in racket sports than in the cricket bowling delivery kinematics, where the delivery arm is partially hidden until shortly before release (Penrose and Roach, 1995). In baseball pitching, where the pitching motion is fast, compact and conceals the ball from the batter, Ranganathan and Carlton (2007) concluded that even expert baseball batters based their prediction of ball type (fastball or change-up) on early ball flight rather than the pitching kinematics, nevertheless the timing of the expert batters' movement responses *were* initiated in response to the pitcher's movements.

Penrose and Roach (1995) found that expert cricket batters were able to predict the line of a delivery longer before ball release than they could predict its length, and also that by the moment of release novice and intermediate batters were doing better than guessing and were approaching similar length prediction accuracy to experts. However, the deliveries displayed for the study averaged a speed of only 25 $m.s^{-1}$ and might therefore not have provided a significant challenge. Müller et al. (2006) appeared to find that batters of all levels required at least some early flight information to improve their ball length predictions against swing bowling. The swing bowler in their study was of a first-class standard but they did not report the actual bowling speed. Batting against moderately fast (approximately 30 to 33 $m.s^{-1}$) swing bowling Müller et al. (2009) found that high-skilled batters were able to use pre-release information to improve length judgement when the ball was bowled short, but both high- and low-skilled batters relied on early ball flight for full deliveries.

When trying to identify different types (but not lengths) of wrist spin delivery Renshaw and Fairweather (2000) found that flight information from 80 ms after ball release (equating to approximately 1.5 to 2.0 m of flight) to the point of bouncing did not enhance their expert batters' abilities to discriminate. The bowler was filmed using an S-VHS video camera, therefore it was highly unlikely to be precisely 80 ms of flight (two fields of the recording) included, and may even have approached 120 ms in some trials. Müller and Abernethy (2006) and Müller et al. (2006) however found that even highly skilled batters make use of ball flight rather than pre-delivery kinematics to decide upon ball length and type when facing the slower pace of spin bowling. This has parallels with the studies of tennis players by Shim et al. (2005) and Triolet et al. (2013) noted previously, where anticipation was not used if time allowed ball direction to be observed.

Both Weissensteiner, Abernethy, Farrow and Müller (2008) and Brenton, Müller and Mansingh (2016) examined cricket batting anticipation using an adaptation of "Experiment 1" from Müller et al. (2006) in which the batters had to predict ball type (inswing or outswing) and length (full or short) from viewing video of a first grade adult seam bowler. Weissensteiner et al. (2008) investigated both the age and skill level influences on batters using a written choice response while Brenton et al. (2016) looked at skilled performers of three different ages and required participants to use a coupled, batting response. Weissensteiner et al. (2008) found some support for the idea that skilled under-20 and adult batters could anticipate ball type at the point of release, but none of the groups could predict ball length at greater than chance levels at this point. Brenton et al. (2016) claimed that only their highly skilled batters performed better than guessing at the point of release, although the difference between the highly skilled and the elite club batters appeared to be almost indistinguishable on their figure, however both were clearly better than the elite youth (17-19 year olds) batters. Surprisingly they showed that even with no occlusion none of the three groups exceeded approximately 60% accuracy for judging ball type whereas in the Müller et al. (2006) and Weissensteiner et al. (2008) studies only the youngest low-skilled group failed to exceed 70% accuracy with no occlusion (and then only on the judgement of length).

In a tennis-based study Farrow and Abernethy (2003) verified Penrose and Roach (1995)'s view that a coupled, rather than written, response to anticipation tasks was particularly beneficial to skilled performers, while Ranganathan and Carlton (2007)'s results from a baseball batting study were less clear. Differences between the requirements of the coupled tasks in these two studies and the nature of the visual information presented to the participants (a live tennis player serving compared with a basic computer animation of a baseball pitcher, without grip or ball spin information) are bound to have influenced the outcomes.

Mann, Abernethy and Farrow (2010) explored a range of response methods (verbal reporting, body movement, body movement with a bat, and actual batting) to signal skilled and novice cricket batters' predictions of the oncoming ball direction. They found that only the skilled batters' anticipation improved as the response method more closely replicated the natural sporting response, that is to say the experts' best performances were when responding with a cricket shot. This would suggest that the outcomes of expert-novice comparisons where the response was not closely coupled to the natural setting may underestimate expert anticipatory advantage.

Rather than use traditional occlusion Pinder, Renshaw and Davids (2009) studied young, non-expert cricketers (average age 15.6 years) batting against bowlers of the same age and comparable standard, as well as against a bowling machine adjusted to mimic the pace, lines and lengths of the bowlers, thus removing all pre-delivery information. Although the extent of early information pick-up by younger or less-skilled batters has been debated, they found differences in timing, coordination and movement magnitude for both defensive and attacking shots when batting against the bowlers compared with when batting against the bowling machine. This indicated that the batters did indeed have some ability to derive useful information from the bowlers' pre-delivery kinematics to assist their shot selection and performance.

Occlusion studies in which occlusion occurs at a specific time pre/post release are affected by the pace of the bowler/server/etc., i.e. 80 ms post-release includes more of the flight at ball speeds of 36 $m.s^{-1}$ than 25 $m.s^{-1}$. Furthermore occlusion-based studies may select batters/receivers of very different standards, but the real or virtual "opponents" are often of a higher standard (and consequently greater pace) than the novice/non-experts/younger batters/receivers would be used to (e.g. Brenton et al., 2016; McLeod, 1987; Müller et al., 2009, 2006; Ranganathan and Carlton, 2007; Renshaw and Fairweather, 2000; Weissensteiner et al., 2008) or offer a very comfortable pace for the high-standard/expert participants (for example Penrose and Roach, 1995), therefore the results may have some bias. Nevertheless these studies suggest that anticipation is characteristic of expert performance and that the ability to pick up early cues may be driven by need, therefore unless or until the usual performance environment places sufficient temporal demand upon players, the need to develop this anticipatory behaviour is unlikely to become evident.

2.5.3 TEMPORAL DEMAND

The apparent ability of skilled performers to use pre-delivery kinematics and even situational probability may be in part due to necessity: experts generally have limited time (elite bowlers are faster, elite tennis players hit harder and so on), therefore they need to pick up early information to guide their responses or to eliminate obviously inappropriate choices (for example front foot shots to short deliveries in cricket). As Mann, Abernethy, Farrow et al. (2010) put it: "skilled athletes effectively "make time" via superior anticipation" (p. 556).

From a cricket perspective Müller et al. (2009) explained:

> Positioning the body is critical for achievement of efficient bat–ball interception. A definitive movement of the foot forward is required to a ball of full length and backward to a ball of short length. When time stress is imposed upon the batsman through fast ball velocity, forward and backward foot movements need to be decisive in order to allow early body positioning. (p. 649)

In games between younger or lower standard players the time constraint is generally less severe so they have less, or possibly no, need to anticipate, much like higher standard players in less demanding situations as mentioned previously, for example Cañal-Bruland and Mann (2015), Müller and Abernethy (2006), Shim et al. (2005) and Triolet et al. (2013).

Despite Müller and Abernethy (2012) suggesting that non-experts *cannot* use early information from opponent's movement pattern to anticipate, they also pointed out that skilled anticipation is a "more important contributor to successful performance the higher the level of competition and the greater the time pressure involved" (p.179). In the case of junior batters on current pitch lengths the time pressure is not great; according to Weissensteiner et al. (2008) "anticipatory skills may be less important in junior competition levels as the bowling speeds are generally slower and may not impose sufficient time constraints to make advance judgments on the basis of pre-release information necessary for success" (p. 681).

In their investigation of protective responses to balls projected towards the head Lipps et al. (2013) demonstrated that temporal demand can be increased by reducing distance rather than increasing speed. Ball and Glencross (1985) investigated coincidence timing across a range of ages using an abstract (and now quite primitive) computer task and they discussed the notions of target velocity and target duration, making the point that typically the two are inversely related. However, in circumstances where only the distance between the protagonists is reduced, the target duration is lower while the target velocity is the same. Therefore the target (ball) is within reach or within the striking zone for the same (or a very similar) amount of time as it would be if it were projected from a greater distance, even though it is seen for less time. Reducing the distance provides an incremental means of increasing the temporal demand even though the bowlers might not bowl any faster.

Weissensteiner et al. (2008) implicitly supported the notion of shorter cricket pitches as a means to increase the temporal demand for young batters:

> Time invested in backyard cricket, for instance, may be advantageous to the long-term development of batting expertise because, with the distance from bowler to batsman frequently being closer than normal, the task constraints may be such as to promote the early development and use of anticipatory strategies. (p. 665)

Portus and Farrow (2011) were more explicit stating "If the temporal demands are not sufficiently demanding to encourage anticipatory skill development, consideration to modification of pitch length is warranted" (p. 299).

Ford, Low, McRobert and Williams (2010) found that players rated highly in a cricket batting anticipation task using visual occlusion at ball release were differentiated from the lower rated players by their additional hours of batting experience between the ages of 13 and 15; one might reasonably speculate that this could be due to the additional demands of batting at this age compared with younger ages, and therefore whether increasing the demands sooner might improve anticipation at a younger age.

2.5.4 COINCIDENCE-ANTICIPATION

In order to explore the ability of participants to intercept a moving stimulus accurately, coincidence–anticipation timing tests have been conducted, frequently using variations of the Bassin Anticipation Timer (BAT; Lafayette Instrument Company, Lafayette, IN). This equipment consists of a "runway" of lights, usually around 3 metres long, which are illuminated in sequence to simulate the motion of an object towards a target point. The participants must attempt to coordinate their response (often a button press, but occasionally a sport-related movement) with the arrival of the stimulus at the target. By altering the rate at which successive lights are switched on and off, a variety of target speeds and, more rarely, accelerations can be simulated. Whilst the simplicity of the task and the spatial and temporal demands mean that the equipment is limited in terms of ecological validity, a number of comparative studies have been performed exploring coincidence–anticipation timing in which junior participants have taken part.

Several studies using the BAT have demonstrated that coincidence-anticipation improves mainly up to late childhood. Haywood (1980) for example found that 11-13 year old children were similar in coincidence-anticipation ability to young adults, although the test speed was only up to 2.2 $m.s^{-1}$. Benguigui and Ripoll (1998) tested groups of tennis players and "novices" (not ball-game players) aged 7, 10, 13 and 23 years old under three conditions: a constant target speed of 4.17 $m.s^{-1}$; constant acceleration of +2.8 $m.s^{-2}$; and a constant acceleration of -2.8 $m.s^{-2}$. In the accelerated conditions the final speed of the target was 4.17 $m.s^{-1}$ and in all three conditions the participants had a viewing time of 700 ms. They found that timing accuracy improved mainly by 10 years of age and that the accelerated conditions didn't affect the timing accuracy of any group, but that the tennis players had better accuracy scores than the novices. It is likely that similar ball games would also confer an advantage. Benguigui, Broderick and Ripoll (2004) again found improvements in coincidence-anticipation occurred by mainly between 7 and 10 years of age. This time the target speed was only 2 $m.s^{-1}$ but following 600 ms in view, the stimulus could be occluded by varying durations (from 0 to 800 ms) before arrival at the target. All participants were less accurate as occlusion duration increased above 200 ms, but in general the 10 year old, 13 year old and adult groups performed noticeably better than the 7 year old group and were more similar to each other.

In most BAT studies the light track is positioned so that the stimulus travels from left to right in front of the participants, however Williams, Katene and Fleming (2002) oriented the track so that the stimulus came towards the participant, more like most striking tasks in sport. In another move towards greater ecological validity, their tennis player participants used a simulated tennis stroke with a tennis racket to break a beam to coincide with when they anticipated the arrival of the stimulus. Unfortunately the stimulus speeds, 2.68 and 5.36 $m.s^{-1}$, were low compared to those experienced in tennis, but they found that error scores reduced between the 10-11.5 and 12-13 year old groups, and again between the 12-13 and 13-14 year olds, but that the 13-14, 14-15 and 15-16 year old groups were almost indistinguishable.

The BAT has also been used to explore coincidence-anticipation timing differences between 12 to 13 year old players of different sports. Ak and Koçak (2010) compared tennis and table tennis players using a 2 $m.s^{-1}$ anticipation task and found that tennis players were better at coincidence-anticipation, while table tennis players had shorter reaction times. In another comparison Akpinar, Devrilmez and Kirazci (2012) found some evidence for coincidence-anticipation timing among 12 to 13 year olds being specific to their sport's typical demands. Taking tennis, badminton and table tennis as low, medium and high speed racket sports respectively, they conducted BAT tests at 1, 3 and 5 $m.s^{-1}$, giving viewing times (target durations) of 2.2, 0.7 and 0.44 s. The anticipation accuracy of tennis players was best at the lowest speed/longest time, the table tennis players at the fastest speed/shortest time and the badminton players were best at the intermediate speed/duration. Despite the intuitively appealing results, truly sport-specific speeds were not replicated, although the shortness of the light track (2.24 m) meant that the target durations *were* more representative of those in each of the sports.

Kim, Nauhaus, Glazek, Young and Lin (2013) also used a more ecologically valid set-up in their simulated baseball catching task. Again the BAT track was directed towards the participants, either at chest or head height, with stimulus speeds between 7.6 and 12.7 $m.s^{-1}$, giving target durations of between 399 and 251 ms. Players of sports involving coincidence-anticipation between the ages of 11 and 18 years were recruited and required to use baseball catching response (including wearing a mitt) to anticipate the arrival of the stimulus. From a standard starting position they found that timing accuracy, movement onset times and movement times did not vary by age. Coincidence-anticipation timing accuracy and movement speed were unaffected by target location (head or chest height), so understandably movement time was greater for the head high "catches", but participants compensated with earlier movement initiation.

Kim et al. (2013) stated that their results, along with other coincidence-anticipation timing studies (such as those discussed here) "provide strong support for the early development of coincidence-anticipation timing skills (i.e., before the age of 11)" (p.333). In fact given the indications that sport-related (or at least pace-related) adaptations to coincidence-anticipation timing are present by the age of 12 to 13 years it would seem advisable for young players to be challenged with target speeds and durations within the range specific to their sport in order to develop sport-specific coincidence-anticipation skills.

2.6 SUMMARY

Very little research has been reported which relates directly to cricket played by children or young adolescents. Concerns over the potential for injury to fast bowlers in particular have led to workload directives for young fast bowlers, but only one study has considered the effect which the pitch length might have. Nevertheless scaling the dimensions of the playing environment to suit young players has been found to be beneficial in a number of sports, although the means of determining an appropriate scale factor is not straightforward. In sports like cricket, reducing the size of the pitch has some potential to increase the likelihood of injury to both batters and bowlers (if the ball is struck back towards them), however evidence would suggest that this is a small risk and indeed that the increased temporal demand should lead to improved anticipation skills by the batters. Research also suggests that by late childhood or early adolescence coincidence-anticipation skills have developed sufficiently to be able to cope with the temporal demand and in fact may be enhanced by being appropriately challenged at a slightly earlier age.

Despite the difficulty of modifying sports appropriately for young players Reid et al. (2018) posed the question “what other pursuit in youth sport has the potential to nurture learning, enjoyment and health as comprehensively?” (p. 1286).

CHAPTER 3
THE EFFECTS ON JUNIOR CRICKET MATCHES OF REDUCING THE PITCH LENGTH

3.1 INTRODUCTION

The standard length of a cricket pitch is 22 yards (20.12 m) between the stumps at each end (Marylebone Cricket Club, 2017a) a distance equivalent to the antiquated unit of one 'chain'. Below the age of 14, the age by which many young players have begun to play open-age or "senior" cricket, the Marylebone Cricket Club (MCC) and the England and Wales Cricket Board (ECB) recommend slightly shorter pitches and, following trials in their 2016/17 season, Cricket Australia also revised their guidance for junior formats, making a range of changes including shorter pitches than they had previously endorsed (Cricket Australia, 2016). It is unclear how these pitch length recommendations (Table 3.1) were determined: for example simply scaling a full length pitch based on the average height of juniors compared with adults would result in a pitch for under-11 boys approximately 17.8 yards (16.3 m) long rather than the 20 yards (18.28 m) the MCC and ECB have specified, but close to the 16 m recently advocated by Cricket Australia. The MCC acknowledged criticism and debate over the junior pitch lengths in earlier codes of the Laws of Cricket (MCC, 2017b) and removed their recommendations from the 2017 Code effective from 1st October 2017 (MCC, 2017a) leaving governing bodies to make their own recommendations. However, to date no research has been published which quantifies the effects that playing on shorter pitches might have on junior matches.

In the only study to consider reduced cricket pitch lengths for junior players, Elliott, Plunkett and Alderson (2005) examined under-11, under-13 and under-15 bowlers when bowling as fast as possible on full length (20.12 m/22 yard), 18 m (19.7 yard) and 16 m (17.5 yard) pitches in a laboratory environment. They found all age groups to be more accurate on shorter pitches and the under-11 and under-13 bowlers to use actions they deemed to be "safer" on shorter pitches. They commented that bowling

Table 3.1. MCC, ECB and Cricket Australia pitch length recommendations for junior cricket.

	MCC (2015)	ECB*	Cricket Australia**
Under-7		16 yd / 14.6 m	
Under-9	18 yd / 16.5 m	18 yd / 16.5 m	15.3 yd / 14 m
Under-10		19 yd / 17.4 m	
Under-11	20 yd / 18.3 m	20 yd / 18.3 m	17.5 yd / 16 m
Under-12		21 yd / 19.2 m	
Under-13	21 yd / 19.2 m	21 yd / 19.2 m	19.7 yd / 18 m
Under-14		22 yd / 20.1 m	22 yd / 20.1 m
Under-15		22 yd / 20.1 m	22 yd / 20.1 m

Note: Age groups- MCC and ECB are based on age at midnight on August 31st of the preceding year, Cricket Australia are indicative only. *Retrieved August 2016 from http://www.ecb.co.uk/sites/default/files/ecb-recommendations-for-junior-cricket-521.pdf **Retrieved April 2017 from http://www.community.cricket.com.au/clubs/junior-formats/format-summary.

with a correct action is more likely when the performance demands are reduced by shortening the pitch, but concluded that both under-11 and under-13 players should play on 18 m pitches as their actions were not statistically significantly better on the 16 m pitch.

The recommendation of Elliott et al. (2005) is close to the 19 and 20 yards the ECB currently recommends for under-10 and under-11 players respectively. Nevertheless many bowlers of this age have difficulty over these distances, with numerous deliveries being unplayable by the batters and difficult for the wicket-keepers to take cleanly. The playable balls are often hit to Mid-wicket by batters benefitting from ample time to play to their strengths and limiting the involvement of fielders in other areas. At a time when cricket is embracing exciting forms of the game, junior cricket can have prolonged spells where little meaningful activity takes place and, as one former England Test player put it, “it looks nothing like senior cricket” (G. Thorpe, personal communication, 7 November, 2014).

Modifying the structure, rules, facilities and/or equipment of sports has been termed “competitive engineering” by Burton, Gillham and Hammermeister (2011) and is aimed at promoting “positive youth sport experiences” (p. 215) by increasing player engagement, retention and skill development. In junior flag-football, Burton, O’Connell, Gillham and Hammermeister (2011) found that playing with a more appropriately sized ball and introducing a “delayed rush” rule change to aid the offensive team more than doubled the scoring, increased the number of scorers by 75% and more than halved player drop-out. Perhaps unsurprisingly Talpey, Croucher, Mustafa Finch (2017) found that opportunities for players to participate and express their skills were significant contributors to keeping junior cricketers playing the game. The data at their disposal didn’t allow analysis of fielding participation or performance, but as cricketers of all ages generally field for longer than they bat or bowl, it would seem likely that regular fielding involvement during matches would also predispose players to continue playing. While Martens, Rivkin and Bump (1984) increased the opportunities for batters and fielders to develop their skills in under-10 baseball matches by having a coach pitch the ball rather than an opposing player, this obviously didn’t enable pitching skills to be practiced competitively. Farrow and Reid (2010) found that scaling down the court increased hitting opportunities for young tennis players, which in a cricket context would benefit the batters and also result in more fielding involvement. They, and more recently Timmerman et al. (2015), also noted overall that scaling the playing environment resulted in a more engaging experience for young tennis players.

Morley et al. (2016) highlighted the lack of empirical research comparing traditional and modified games in a competitive setting; however they also acknowledged the inevitable difficulties of field-based research of this kind. Different sample sizes and lengths of interventions between conditions, and understanding which of several interventions may have led to the changes observed were all limitations they noted in their study. These difficulties must be weighed against the "the more representative performance… observed during match-play conditions" (Farrow, Buszard, Reid and Masters, 2016; p. S21). Recognizing this challenge, the approach in the current study was to focus on one modification, pitch length, a limited age range of players and a small number of objective measures of bowling, batting and fielding (the three main components of cricket). From these measures the potential for playing on shorter pitches to enhance junior cricket could be evaluated.

Specifically it was anticipated that shorter pitches would: increase the number of playable deliveries bowled (i.e. not Wide or bouncing more than once) although the number of full toss No balls (balls reaching the batter above waist height without bouncing) might also increase; increase the number of shots attempted by the batters; increase the amount of running by batters; reduce the number of boundaries and shots to the Mid-wicket area; and result in a more even involvement of outfielders (i.e. excluding the wicket-keeper and bowler).

3.2 METHODS

3.2.1 PARTICIPANTS

An English county cricket board agreed to facilitate the study by playing their three county under-10 boys' home matches on a reduced pitch length. The Board also gained the agreement of a junior league within the county to play all of their under-11 club league matches during the same season on the same length of pitch. A total of 155 players participated in the short pitch matches and 153 in the existing pitch length matches (Table 3.2). Assent from the participants and informed consent from their parents was obtained, and ethical approval was obtained from the university.

The under-11 age group (based on a player's age at midnight on 31st August of the preceding year) is commonly the entry level for "hardball" club cricket, though some leagues in England start at under-10 or even under-9. In the counties involved in this study, under-10 was the youngest county representative age group team. In club matches boys and girls were allowed to play in the same team, though only 12 girls played in total.

Table 3.2. Match and player details.

	Pitch length (yards)	Number of matches	Number of teams	Match format	Number of players	Player ages (years; mean ± s)
Club	20	7	11	8-a-side pairs	92	10.41 ± 0.98
Club	16	7	10	8-a-side pairs	98	10.46 ± 0.95
County	19	3	5	11-a-side traditional	61	10.08 ± 0.53
County	16	3	4	11-a-side traditional	57	10.15 ± 0.50

Note: Seven club and two county teams played in more than one match (not against the same opponents) but rotated some players. Player ages given at the start of the season.

3.2.2 STUDY DESIGN

A trial pitch length of 16 yards (14.63 m) was chosen by a Level Four county coach on the basis of previous experience, including pilot games conducted prior to the season (Appendix B). Ten matches played on the reduced pitch length were recorded and a further ten (played by five counties and two comparable, neighbouring club leagues) were recorded on the existing ECB recommended pitch lengths (Table 3.2). As only one county was trialling the shorter pitch, that county team featured in each of the three 16 yard under-10 games. Due to the shortness of the junior cricket season in England (approximately 10 weeks), weather and scheduling constraints, four club teams featured twice in the 16 yard and three teams twice in the 20 yard matches. Despite some teams being recorded on more than one occasion, the team members were not identical and the opponents were different. Both club and county matches were analysed as it was considered important to assess whether any effects of shortening the pitch were similar at both club and representational levels.

Club matches were played using an 8-a-side pairs format in which each pair of batters bat for four, six ball overs, with runs deducted for wickets lost but the batters continuing and each fielder (except the wicket-keeper) bowling two or three overs in a 16 over innings. Of the county matches two were scheduled for 40 overs per innings, three for 35 overs per innings and one shortened to 20 overs per innings due to rain. Only seven of the 12 county innings reached their maximum duration, in the other five innings 10 wickets were taken to end the innings before all the available overs had been bowled. A total of 224 overs (approximately 1344 deliveries) of club cricket on each pitch length were observed, the same for county cricket on 19 yard pitches, and 178 overs (approximately 1068 deliveries) of county cricket on 16 yard pitches.

3.2.3 MATCH DATA COLLECTION

An experienced Level Two cricket coach observed all of the matches, completing a ball-by-ball scoresheet including runs scored, Wides and No balls, (no player names were attached to the data). To assess shot distribution, the playing field was notionally divided into seven areas: the wicket area (where the ball was fielded by the bowler or wicket-keeper) and six sectors surrounding it (Figure 3.1). A count was kept of the number of times the ball was played into each of these areas during each innings. In addition, a Panasonic DMC-FZ200 camera was positioned just outside of the boundary, approximately mid-way along and perpendicular to the pitch, zoomed in so that the field of view included the length of the pitch from wicket to wicket plus approximately one meter at either end. HD MP4 video at 30 fps was recorded throughout each innings.

During the matches score details were corroborated with the match score as displayed at the ground. In order to assess reliability of the shot distribution data, a second observer independently recorded this aspect of one trial innings and the two sets of data showed that of the 97 deliveries only two were allocated to different (neighbouring) areas (Appendix C). Subsequently the Level Two coach recorded all matches.

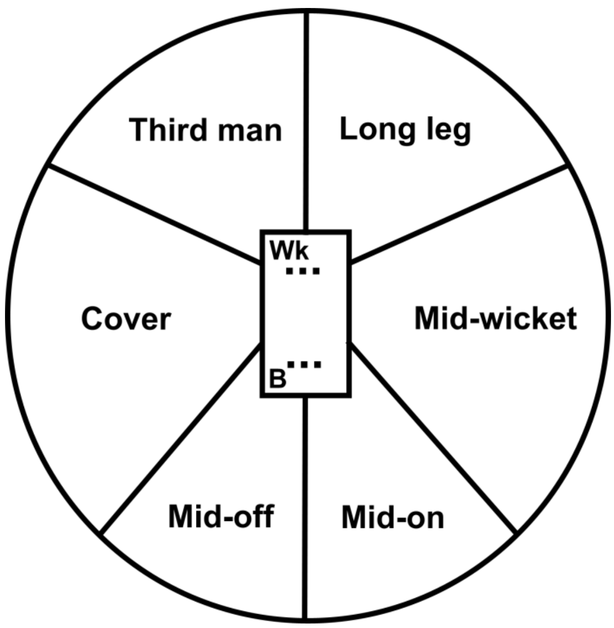

Figure 3.1. Playing field areas for a right-handed batter. (B = bowler; Wk = wicket-keeper).

For every innings the total number of each of the following measures were calculated and expressed per 100 deliveries (i.e. count x 100 ÷ number of deliveries in that innings):

- the number of playable deliveries, defined as those not called Wide by the umpires and which bounced not more than once before reaching the batter (determined by viewing the videos);
- the number of full toss No balls, as determined from the videos;
- the number of attempted shots, whether successful or not, as determined from the videos;
- the number of deliveries which resulted in the batters running one, two or three runs, including extra runs on Wide or No ball deliveries, counted from the scoresheets and checked on the video;
- the number of deliveries hit over the boundary for four or six runs, counted from the scoresheets;
- the number of deliveries played to each of the seven defined areas of the pitch as noted during the matches, and from this the number played to the Mid-wicket area and the overall distribution of shots around the outfield.

Attempted, not just successful, shots were counted (Martens et al. 1984) as this reduced the influence of the relative abilities of the batters and bowlers, which could not be controlled. Similarly any occasion where the batters ran at least one run was recorded, with no importance attached to the actual number of runs scored, thereby limiting the influence of the ability of the fielders. While the number of deliveries hit to the boundary is affected by ground conditions (e.g. boundary distances, grass length, slopes, ground hardness), prior to each match grounds staff in conjunction with team managers or coaches adjust boundary distances according to the prevailing conditions and over a number of matches any minor influences are mitigated.

3.2.4 DATA ANALYSIS

SPSS (version 22) was used to check for normality (Shapiro-Wilk test), equality of variance (Levene's test) and outliers, as well as to calculate means, standard deviations, differences between means (16 yard pitch – current length) and 95% confidence intervals for the differences. In county matches on 16 yard pitches the full toss No ball data were not normally distributed, three of the six innings having none at all.

Following the recommendations of Cumming (2014) significance testing was not conducted as it gives no information regarding practical importance or precision of the result, however where the 95% CI does not include zero difference between the means it is equivalent to a statistically significant difference at the $p < .05$ level. To maintain the connection between the measures and the game setting, raw differences between means were calculated as the primary measure of the effects (Baguley, 2009). Effect size interpretation was based contextually on knowledge of the game (Cohen, 1988; Cumming, 2014) with a difference of at least one occurrence per 6-ball over considered to be a large effect (equivalent to 16.6 per 100 deliveries), from that to one every two overs as moderate (8.3 to 16.5 per 100) and from that to one every four overs considered a small effect (4.2 to 8.2 per 100). In the pairs format the batters had four overs to bat, so a difference of one occurrence every four overs was considered to be the smallest meaningful difference and anything smaller was considered to be trivial.

3.3 RESULTS

Playing on a 16 yard pitch increased the number of playable deliveries in the club under-11 matches by 15%, a moderate effect of 11 per 100 deliveries, 95% CI [3.5, 18.6] (Figure 3.2a), the biggest difference being the halving of the number of deliveries bouncing twice or more (Table 3.3), and the number of Wides bowled was also reduced. In the county under-10 matches this effect was absent (Figure 3.2b) with the number of playable deliveries being similar on both pitch lengths and on neither pitch length did the county players bowl any double bouncing balls. Full toss

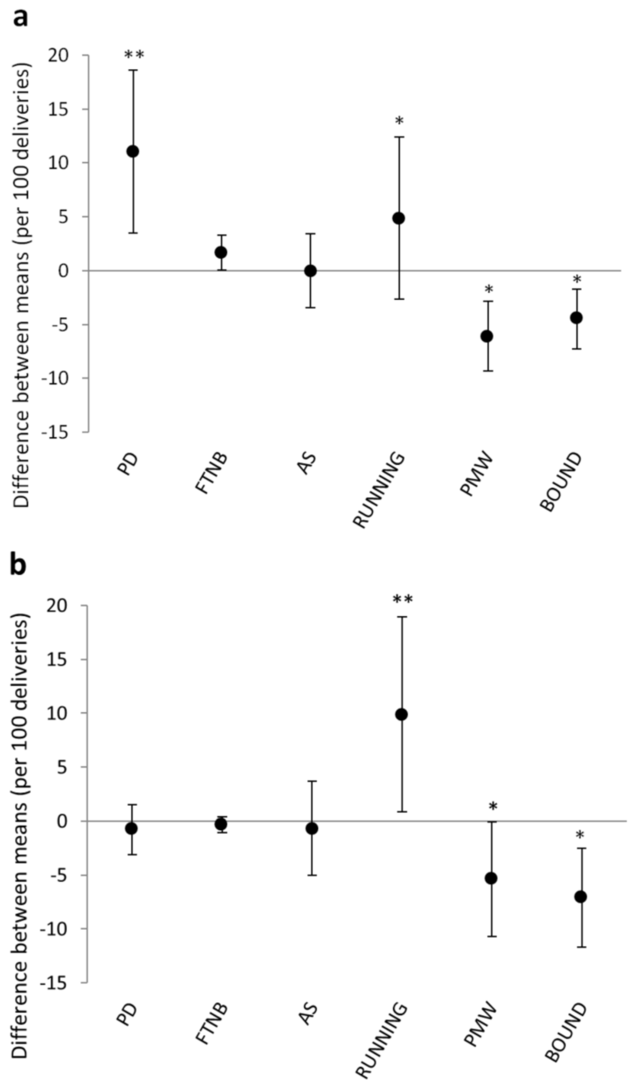

Figure 3.2. Differences between means of measures in (a) club under-11 (16 yard – 20 yard) and (b) county under-10 matches (16 yard – 19 yard) matches. Error bars are 95% confidence intervals; ** indicates a moderate effect size, * indicates a small effect size. (PD = Playable delivery; FTNB = full toss No ball; AS = Attempted shots; RUNNING = deliveries resulting in completed runs; PMW = shots played to Mid-wicket; BOUND = deliveries resulting in boundary 4s or 6s).

No balls occurred rarely in any of the four match conditions and only trivial differences were apparent between pitch lengths.

There was an increase in the amount of running activity by batters on 16 yard pitches despite there being no overall difference in the number of shots attempted (Table 3.3). In the county games on short pitches, running events increased by 9.9 per 100 deliveries, 95% CI [0.82, 18.1], a 39% change (a moderate effect), and in the club games there was a 22% increase of 4.9 per 100 deliveries [-2.7, 12.4], a small effect (Figures 2a and 2b). On the shorter pitches the number of boundaries was reduced by 7.1 per 100 balls [2.5, 11.7], or 68%, in county matches and 4.5 per 100 balls [1.7, 7.2], or 54%, in club matches, small effects in both cases.

The number of deliveries played to the Mid-wicket area decreased on the 16 yard pitches in both club and county matches, by 6.1, 95% CI [2.9, 9.3], or 44%, and 5.4, [0.1, 10.7], or 33%, per 100 deliveries respectively, again small effects. The shorter pitch length resulted overall in a more even distribution of outfield fielding opportunities (excluding the balls which go through to the wicket-keeper or are played back towards the bowler). This is shown by a reduction in the standard deviation of the number of times balls were played to the various field areas of 3.5, [1.9, 5.2], 36%, in club matches and 1.4 [-2.0, 4.8], 15%, in county matches (Table 3.4; Figures 3.3a and 3.3b).

Table 3.3. Summary game measures for each of the match formats (mean ± s, per 100 deliveries).

	Wide	Double Bounce	Playable Deliveries	Full toss No ball	Attempted Shots	Running	Played to Mid-wicket	Boundaries
Club 20	10.2 ± 4.8	18.5 ± 7.8	71.4 ± 9.6	1.7 ± 1.5	89.1 ± 4.9	22.4 ± 8.4	14.0 ± 5.5	8.2 ± 4.2
Club 16	8.6 ± 5.0	9.4 ± 7.6	82.4 ± 9.9	3.4 ± 2.5	89.1 ± 3.9	27.3 ± 10.8	7.9 ± 2.1	3.7 ± 2.8
ES	-1.6	-9.1**	11.0**	1.7	0.0	4.9*	-6.1*	-4.5*
County 19	2.6 ± 1.7	0.0 ± 0	97.4 ± 1.7	0.8 ± 0.6	95.1 ± 2.0	25.3 ± 7.1	16.2 ± 5.1	10.3 ± 4.5
County 16	3.4 ± 1.9	0.0 ± 0	96.6 ± 1.9	0.5 ± 0.5	94.4 ± 4.3	35.1 ± 7.0	10.8 ± 2.9	3.2 ± 2.3
ES	0.8	0.0	-0.8	-0.4	-0.7	9.9**	-5.4*	-7.1*

Note: ES= raw effect size; **= moderate ES; *= small ES. Positive ES indicates a higher count in the short pitch matches.

Table 3.4. Frequencies with which deliveries were hit to each pitch area and variability with which outfield areas were involved (mean ± s, per 100 deliveries).

	Wk/Bowler	Long Leg	Mid-wicket	Mid-on	Mid-off	Cover	Third Man	Outfield SD
Club 20	52.3 ± 10.2	10.6 ± 5.1	14.0 ± 5.5	5.1 ± 1.9	3.0 ± 2.2	9.5 ± 3.3	5.4 ± 2.0	9.7 ± 2.5
Club 16	49.0 ± 9.3	11.3 ± 3.8	7.9 ± 2.1	7.8 ± 3.5	7.0 ± 4.2	9.1 ± 3.5	7.9 ± 3.3	6.2 ± 1.8
County 19	36.6 ± 5.5	8.1 ± 2.1	16.2 ± 5.1	5.8 ± 2.3	7.2 ± 2.1	20.1 ± 6.6	5.9 ± 2.1	9.5 ± 3.4
County 16	42.5 ± 2.4	6.4 ± 1.7	10.8 ± 2.9	5.7 ± 3.1	8.6 ± 2.2	17.9 ± 1.7	8.1 ± 3.7	8.1 ± 1.6

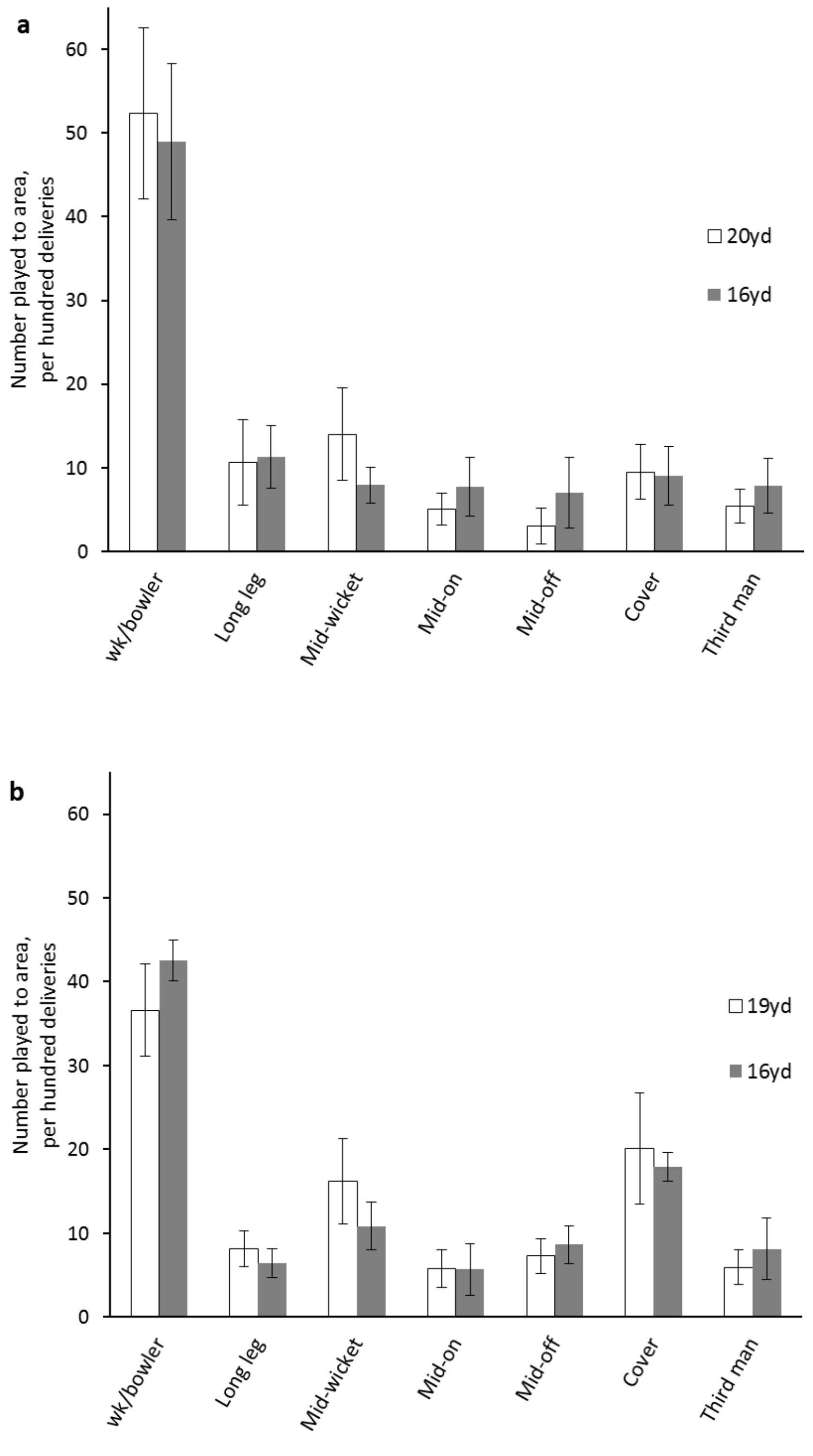

Figure 3.3. Mean number of balls played to each area of the field in (a) club under-11 and (b) county under-10 matches. Error bars indicate standard deviation.

3.4 DISCUSSION

This study assessed for the first time the effects of playing junior cricket on a shorter pitch length using a number of straightforward measures of bowling, batting and fielding. County under-10 matches (16 yards compared with 19 yards) and club under-11 matches (16 yards compared with 20 yards) were analysed separately, and shortening the pitch improved outcomes in both standards of competition.

Lee and Smith (2003) stated “In cricket the use of short pitches allows bowlers to be more accurate which itself benefits batsmen because the ball will arrive more often in the striking area.” (p. 265). The belief that playing on shorter pitches would increase the number of playable deliveries was borne out in club (a 15% increase) but not county matches; this was due mostly to the reduction at club level of deliveries bouncing twice or more (Table 3.3). Double bouncing deliveries are difficult for batters to play, occasionally inducing a play and miss resulting in being bowled, and moreover are disheartening for bowlers. Shortening the pitch should lead to greater efficacy and self-efficacy on the part of bowlers, similar to that found when basket height was modified in basketball (Chase, Ewing, Lirgg and George, 1994).

The difference between the numbers of double bounce deliveries in club and county bowling may be explained by the fact that under the club match rules everyone in the fielding side except the wicket-keeper bowls, whilst in county games a minimum of five players from the eleven must bowl (and naturally the best bowlers are chosen). Furthermore county bowlers have effectively been selected *because* they can cope with the current pitch length for their age group, possibly because of better technique, but also perhaps because they are comparatively tall. It proved impractical to measure individual stature for this study, but the median stature of the county under-10 and top club under-11 bowlers the bowling study (Chapter 4) was 58th centile for their age (Appendix D). This study did not look at how the shorter pitch may have affected bowling technique and associated risk of injury, but it is likely that even county bowlers bowled with better and safer technique on the 16 yard pitches, in line with the findings of Elliott et al. (2005), who looked at pitches down to 17.5 yards (16.0 m).

Unexpectedly, the number of Wide balls was not very different between pitch lengths in either standard of match. However it became apparent while recording club matches (where coaches and parents rather than qualified umpires take charge) that the calling of Wide balls was inconsistent and had a tendency to be lenient with the weaker bowlers. If the calling of Wides in club matches had been stricter, it is likely that the playable deliveries count on the longer pitches would have been lower and consequently the beneficial effect of playing on short pitches larger.

By quantifying attempted shots rather than just successful contacts the engagement of the batters was considered, regardless of the relative skill levels of batter and bowler. Even an unsuccessful shot demonstrates that the batter is engaged with the game, as Martens et al. (1984) put it "…the player at least did something…swinging and missing is unquestionably the first step towards swinging and hitting." (p. 353); it is better still if the swing and miss is at a delivery which is accurate enough to give the batter a reasonable *chance* of success. Overall in neither club nor county matches were there differences between the numbers of attempted shots on the different pitch lengths. However the frequency of double bouncing deliveries and the leniency in calling deliveries as Wide leads players in club matches (perhaps out of frustration) to attempt to play at some balls with which they have little hope of making effective contact. This is illustrated by the substantially higher rate of attempted shots compared with the rate of playable deliveries in club matches, particularly on the longer pitch length (Table 3.3).

One concern associated with playing on a shorter pitch was that the response time of batters is reduced and "full toss No balls" (deliveries which reach the batter above waist height without bouncing) could potentially be more dangerous and more frequent. However, compared with the longer pitches, full toss No balls on the shorter pitches were no more frequent in county matches and were only slightly, but trivially more frequent in club matches. No instances of injury occurred in the recorded matches and no reports of any were received from the other approximately 45 club matches played between the 13 teams in the under-11 league playing on 16 yards during the season.

The clear increase in running between the wickets on shorter pitches in club and county matches (22% and 39% increases respectively) is a very positive outcome. Judging when to run, communication between batting partners and “rotating the strike” (frequently changing which of the two batters is facing the bowler) are all features which coaches seek to encourage. The bigger effect size in county matches is probably explained by the better judgement by these players of when to run and better communication between partners. More running (and attempted and “considered” runs) by batters also results in more demanding fielding opportunities (defensive involvement), as Spieth (1977) and Martens et al. (1984) also found in baseball studies. The fielding involvement is both direct (where the fielder gathers the ball straight from the bat) and indirect (where fielders have to “back up the throws” from the first fielder towards the stumps). The more frequently batters run (or consider running), the more alert and engaged all fielders need to be, the more attempted run outs there should be and ultimately the more excitement there is. Balls hit over the boundary were excluded from the measure of running as very often there is little meaningful activity involved for batters or fielders once the ball has been struck, rather like being ‘aced’ in tennis.

It was anticipated that on shorter pitches a combination of the slightly reduced time available to the batter, and the naturally fuller length and improved accuracy of the bowlers would limit the opportunity for batters to hit to Mid-wicket, the favourite area for young club cricketers in particular, and limit the number of boundaries scored. The reduction in the number of balls played to Mid-wicket and boundaries scored was clear in both club and county matches on short pitches, furthermore the distribution of where balls were played to around the outfield was more even. Keeping more fielders more involved has motivational benefits as recognized in the basis for competitive engineering (Burton, Gillham, et al., 2011) but also gives more opportunities to practice fielding skills and a greater incentive to become better fielders. From a team perspective, reducing the dominance of one area of the outfield also makes it less attractive for the best fielders to monopolize it, plus spreading the fielding opportunities around more reduces the effect on individuals of isolated mistakes by providing chances to “make amends” for them. The need to be able regularly to play the ball into all areas of the field should also lead to more rounded stroke development in batters as they adapt to the functional instability the shorter pitch introduces (Fitzpatrick, Davids and Stone, 2017).

As acknowledged by Morley et al. (2016), collecting data in a natural, competitive environment has an impact on the control of data collection. In this study the number of teams trialling the 16 yard pitch, the scheduling of matches and weather cancellations limited the number of matches which could be observed, nevertheless the number of deliveries, in excess of 1000 in each of the four cases, was substantial. Another limitation was the inability to control the number of balls faced by each batter and which bowlers bowled at them, though in club matches each pair of batters was limited to four overs between them. Furthermore, although measures were chosen to limit subjectivity, control of the consistency of the umpiring of club matches was not possible. These factors are likely to have reduced the precision in the results somewhat (as illustrated by the size of the confidence intervals and standard deviations in Figures 3.2 and 3.3 respectively), nevertheless meaningful effects were clearly found.

Boundary sizes particularly affect the ability of batters to hit fours and sixes, and also the "density" of the fielders. While they were not at fixed distances and were not recorded as part of this study, they were set by the team managers, coaches and grounds staff for each match based on their experience and the conditions pertaining at each match. Boundary size guidelines exist but allow great flexibility, for example between 30 and 55 m from the pitch for under-13 boys (England and Wales Cricket Board, 2017) Like pitch lengths, boundary sizes for junior cricket should be subject to further research as they too are task constraints which influence player development.

The choice of 16 yards as the shorter pitch length in this study was made by a very experienced county cricket board coach and having found benefits for all facets of the game over a range of playing abilities it is likely that it is close to the optimal pitch length for under-10 and under-11 players. Further research is ongoing to attempt to determine optimal pitch lengths across junior age groups in an effort to make the pitch lengths suit the players as they mature physically and technically.

In common with studies which investigated scaling in junior tennis (Farrow and Reid, 2010; Timmerman et al., 2015), reducing the pitch length resulted in a more engaging game where players had more opportunities to develop their batting and fielding skills, as well as achieving more success when bowling. While Timmerman et al. (2015) and Limpens, Buszard, Shoemaker, Savelsbergh and Reid (2018) found that scaling the tennis court and/or the net resulted in a more attacking style of play, the influence of the shorter pitches was less clear cut. There were fewer clearly attacking shots (e.g. boundaries) by batters but arguably more attacking bowling, certainly in terms of length even if not so clearly in line. The greater urgency in running between the wickets can also be seen as a more attacking approach by the batters.

The overall feel of the games on shorter pitches was more like that of adult cricket which is a feature of appropriately scaled junior sport (Buszard, Reid, Masters and Farrow, 2016). It is hard to quantify the 'intensity' of the games that was apparent to participants and observers of the 16 yard matches but informal, subjective feedback from them made it clear that the matches were more fun and a more absorbing experience. This was perhaps best summarized by one young club cricketer who was quoted as saying to his team manager after a game "It's like a proper match. When is the next one?" (M. Lomas, personal communication, August 2015).

3.5 CONCLUSIONS

Marking out a shorter pitch is a simple and very cost effective example of competitive engineering. Playing on a shorter pitch than is currently recommended benefitted club under-11 and county under-10 batters and fielders, as well as club level bowlers. For county standard bowlers the shorter pitch made little difference, however their ability to cope with a longer pitch was effectively a prerequisite for their selection to play at that level. Overall the combination of objectively measured improvements led to games which were more engaging and it is clear that if juniors played on shorter length pitches their enjoyment and experience of cricket would be improved. While these clear improvements were found, the 16 yard pitch trialled may not have been optimal for these players and research to determine optimal lengths for all junior age groups is required. Coaches and governing bodies should consider reducing the pitch lengths played on as a simple way to encourage desirable outcomes for young cricketers.

CHAPTER 4
DOES SHORTENING THE PITCH MAKE JUNIOR CRICKETERS BOWL BETTER?

4.1 INTRODUCTION

Bowlers try to deceive batters with a combination of speed, movement in the air and movement off the pitch. Pace or seam bowlers must bowl the ball into the surface to get the ball to bounce and/or move sideways off the pitch; as Woolmer, Noakes and Moffett (2008) put it "to get the seam to bite and bounce, you need to hit the deck hard" (p. 253). In other words, a greater downward component of velocity elicits more bounce and increases the chances that the ball will deviate from its line when the raised, stitched seam of the cricket ball hits the pitch.

Adult emerging national pace bowlers, playing on 22 yard (20.12 m) long pitches, bowl the ball at an angle typically around 7° below the horizontal for their standard deliveries (Cork, Justham and West, 2012; Justham, West and Cork, 2008; Worthington, 2010). The current recommendations for junior pitch lengths range from 18 yards (16.46 m) at under-9 to 21 yards (19.20 m) at under-13, with older juniors playing on a full length pitch (MCC, 2015). Despite playing on these slightly shorter pitches, many otherwise competent junior bowlers still appear to struggle to project the ball the required distances with good technique. In order to achieve the distance they often release the ball travelling close to or even above the horizontal, not directing the ball *into* the pitch as the best adults do. The debate about junior pitch lengths has been acknowledged by the Marylebone Cricket Club (MCC, 2017b) and they have removed their recommendations from the 2017 Code of the Laws of Cricket (MCC, 2017a) leaving governing bodies to determine the pitch lengths (Law 8.4) from October 2017 onwards.

Cricket Australia trialled wide ranging changes to their junior formats for their 2016-17 season which included reducing pitch lengths to between 14 m (15.3 yards) for 7 to 10 year olds, and 17.7 m (19.4 yards) for under-14s. These have subsequently been revised to 14, 16 and 18 m for under-9s, 11s and 13s respectively

(Cricket Australia, 2017), although research quantifying the specific effects of bowling on shorter pitches is sparse. Elliott, Plunkett and Alderson (2005) found that when asked to bowl as fast as they could on three pitch lengths, junior fast bowlers were more accurate and under-11s and 13s also bowled with a safer technique on 16 and 18 m pitches compared with 20.12 m. They found that ball speed did not change significantly, although only three deliveries per bowler on each of three pitch lengths were analysed.

Other sports also modify the dimensions of aspects of the playing environment in junior age groups (e.g. tennis, baseball, basketball) and in their review Buszard, Reid, Masters and Farrow (2016) highlighted the potential benefits of scaling equipment and play areas to suit junior participants, while noting the general lack of empirical evidence underpinning such changes.

Shortening the pitch could be a straightforward way to help young cricketers to bowl more like elite players, releasing the ball with a more downward trajectory and consequently achieving greater success and enjoyment. However, bowlers might adjust their range by altering the ball release speed, although the results of Elliott et al. (2005) did not support this. Changes to release position also affect the range of the ball, but release position is constrained by an individual's size and the bowling action itself.

The purpose of this study was to quantify the effect of altering the pitch length on ball release position, speed and angle in bowling by junior seam bowlers and the consistency of these parameters. It was anticipated that the bowlers would adapt the angle at which the ball was projected, releasing the ball with a more downward trajectory on a shorter pitch, rather than by adjusting bowling speed or changing the point of release. It was also anticipated that variability in the release parameters would be reduced on the shorter pitch.

4.2 METHODS

Twenty male, junior, right-arm seam bowlers (aged 10.8 ± 0.63 years; height 1.46 ± 0.058 m; Appendix D), agreed to participate in the study, having been identified by their county or club coaches as being the best in their age group squads. The study was approved in accordance with university ethics committee guidelines and once the procedures had been explained to them, informed consent was obtained from the players and their parents.

The study was conducted at an indoor cricket facility on a synthetic grass surface (Supergrasse™ Shield), which has a 9 mm pile height and is laid on a concrete base (Figure 4.1). The layout of the hall enabled the bowlers to use their full run-up. Following their individual bowling warm ups and familiarization with the testing procedure, each player bowled 12 deliveries (two "overs") on each of two different pitch lengths. Half of the group bowled their first 12 balls on 19 yards (17.37 m), followed by 12 balls on 16 yards (14.63 m), and the pitch length order was reversed for the other half of the group. Nineteen yards was the England and Wales Cricket Board recommended length for the under-10 age group that 16 of the bowlers had been in during that season (four club bowlers were from the under-11 age group) and 16 yards was chosen by a Level 4 coach following a pilot study with a county under-10 squad.

Figure 4.1. Data collection environment.

The players were asked to bowl good length balls at their usual pace (aiming to bowl so that the ball bounced and passed or struck the stumps at close to stump height). They rested between deliveries as they desired and had a number of practice deliveries according to their individual needs (typically two or three) when the pitch length was changed. The total number of deliveries per bowler complied with the ECB Fast Bowling Match Directives (England and Wales Cricket Board, n.d.-b).

An 18 camera Vicon Motion Analysis System operating at 300 Hz was used to track 14 mm diameter spherical reflective markers attached to the left heel, medial and lateral epicondyles of the right wrist and back of the right hand. Two 24 x 24 mm square patches of reflective tape were placed diametrically opposite each other on the new four-piece leather 135g junior cricket balls (GM "Clubman") used in the study. The system z-axis was in the upward vertical direction, the y-axis was defined to be parallel to the long axis of the pitch, with the positive direction being measured from the bowling (or "popping") crease towards the batting end, and the x-axis was mutually orthogonal to y and z, positive from left to right from the bowlers' perspective. The calibrated volume included at least four steps prior to ball release and over 3.50 m of ball flight. Prior to the bowling trials, a static trial was recorded for each individual with the ball held at the tips of the first and middle fingers, as if just being released (Figure 4.2). This was used to calculate the distance between the ball and wrist centres (mid-point of the two epicondyle markers) at release.

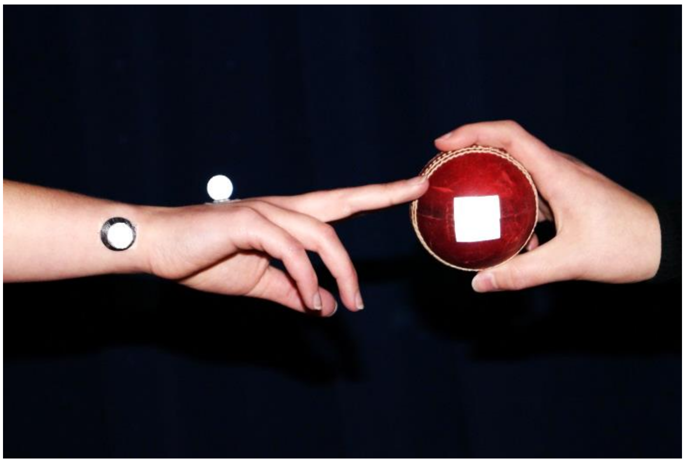

Figure 4.2. Ball release static trial.

Ball release was taken to be the first frame where the ball-wrist centre distance exceeded the value from the bowler's static trial. Raw wrist epicondyle positions were not smoothed as calculating the mid-point of the two to find the wrist centre had a smoothing effect. Throughout the recorded flight, straight line least squares fits were made to ball position with respect to time in the x and y directions, and parabolic least squares fits (with acceleration constrained to be -9.81 $m.s^{-2}$) were made in the vertical direction. This smoothed the raw data and enabled ball position and speed at release in each direction to be determined in a similar manner to Dupuy, Mottet and Ripoll (2000).

The magnitude (release speed) and angle with respect to the horizontal (release angle) of the resultant ball release velocity were calculated, along with the release height as a percentage of stature ("Release Height %"), the left heel position in the y direction at front foot contact ("front foot position"), and the y displacement of the ball at release in relation to the front foot position, again as a percentage of stature ("Release Distance %"; Figure 4.3). As the left heel position at foot contact was required, smoothing of these data was considered inappropriate due to the sudden acceleration.

For each bowler on both pitch lengths, median values were determined as representative of each of the five parameters and standard deviations were calculated as estimates of bowler variability (Fleisig, Chu, Weber and Andrews, 2009). All deliveries were included in the analyses but using median values rather than means reduced the influence of outliers. Within-subject differences between medians and standard deviations for each measure were calculated, followed by the means, standard deviations and 95% confidence intervals of these paired differences for the group of 20 bowlers. SPSS (version 22) was used to perform the Shapiro-Wilk test to check that the data were normally distributed. Additionally standardized effect sizes (Cohen's d with the 19 yard standard deviations as the denominator) were interpreted according to the guidelines of Cohen (1988) where: $d < 0.2$ is "trivial"; $0.2 < d < 0.5$ is "small"; $0.5 < d < 0.8$ is "medium"; $d > 0.8$ is "large". Explicit significance testing was not conducted, however a statistically significant two-tailed difference at the p < .05 level can be inferred where the 95% confidence interval does not include zero difference between the paired differences (Cumming, 2014).

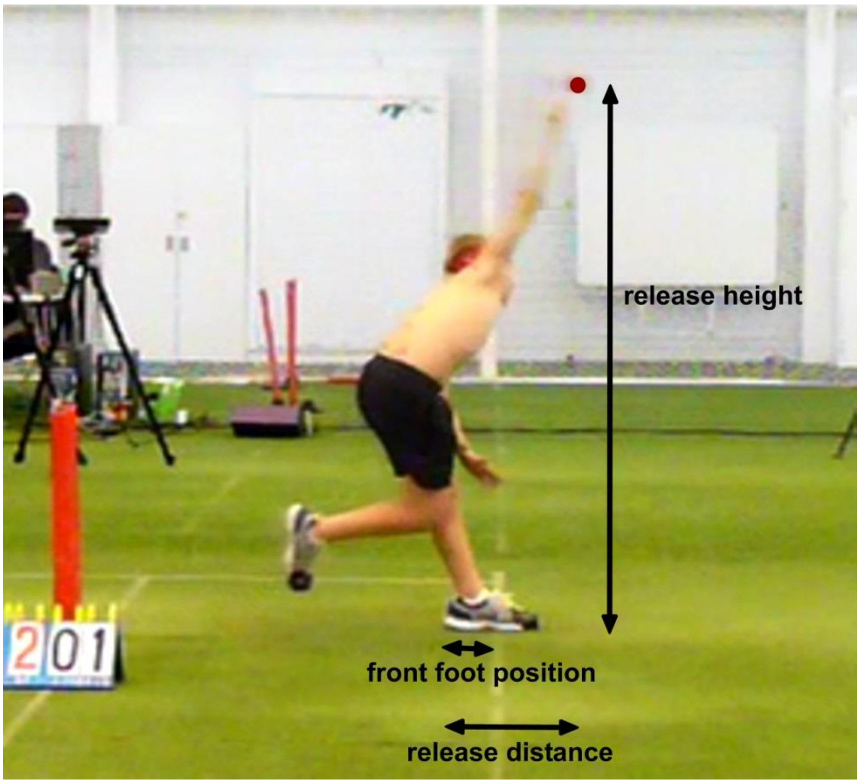

Figure 4.3. Bowler at the point of ball release illustrating release height, release distance and front foot position in relation to the bowling crease.

4.3 RESULTS

The mean of the individual median bowling speeds across all bowlers on both pitch lengths was 21.1 ± 1.41 $m.s^{-1}$ (Table 4.1). The difference between the mean bowling speeds on the two pitch lengths was 0.13 $m.s^{-1}$, 95% confidence interval for the difference was [-0.06, 0.32], and there was a trivial effect size of 0.09 (Table 4.2).

Table 4.1. Ball release parameters for each bowler on 16 and 19 yard pitches, median (standard deviation) and overall mean and standard deviation for deliveries on both pitch lengths.

	Bowler	RelSp ($m.s^{-1}$)		RelAng (°)		RelHt%		RelDist%		FFPos (m)	
16 YARD DELIVERIES	1	21.3	(0.45)	-8.4	(5.2)	109	(0.0)	33	(0.1)	-0.71	(0.23)
	2	20.8	(0.40)	-4.7	(5.0)	105	(0.0)	34	(0.1)	-0.92	(0.16)
	3	19.7	(0.23)	-3.7	(4.1)	114	(0.0)	39	(0.1)	-0.36	(0.07)
	4	19.7	(1.01)	-3.9	(4.0)	110	(0.0)	29	(0.1)	-0.19	(0.15)
	5	23.9	(0.34)	-4.5	(2.1)	107	(0.0)	31	(0.0)	-0.16	(0.06)
	6	21.4	(0.37)	-3.3	(3.2)	105	(0.0)	30	(0.1)	-0.17	(0.06)
	7	17.7	(0.43)	-0.6	(4.3)	119	(0.0)	19	(0.1)	-0.10	(0.08)
	8	20.6	(0.60)	-6.4	(4.0)	114	(0.0)	40	(0.1)	-0.38	(0.21)
	9	21.8	(0.88)	-8.8	(3.6)	109	(0.0)	28	(0.0)	-0.43	(0.08)
	10	20.5	(0.52)	-1.2	(3.5)	117	(0.0)	25	(0.1)	-0.40	(0.31)
	11	22.1	(0.59)	-5.4	(2.5)	115	(0.0)	27	(0.1)	-0.47	(0.07)
	12	20.2	(0.64)	-1.1	(4.3)	107	(0.0)	34	(0.1)	-0.65	(0.14)
	13	21.1	(0.36)	-0.1	(4.0)	114	(0.0)	30	(0.1)	0.09	(0.14)
	14	20.6	(0.44)	-2.9	(4.4)	108	(0.0)	27	(0.1)	-0.25	(0.12)
	15	22.6	(0.41)	-10.5	(6.0)	103	(0.0)	42	(0.1)	-0.27	(0.11)
	16	21.6	(0.35)	0.5	(2.6)	112	(0.0)	14	(0.1)	-0.38	(0.12)
	17	23.4	(0.38)	-6.6	(3.8)	110	(0.0)	35	(0.1)	-0.36	(0.10)
	18	21.4	(0.49)	-0.0	(3.6)	110	(0.0)	34	(0.1)	-0.41	(0.10)
	19	23.2	(0.65)	-6.3	(2.9)	107	(0.0)	34	(0.1)	-0.28	(0.17)
	20	20.7	(0.44)	-5.3	(3.9)	114	(0.0)	41	(0.1)	-0.32	(0.11)
19 YARD DELIVERIES	1	21.4	(0.87)	2.6	(6.1)	112	(0.0)	22	(0.1)	-0.78	(0.16)
	2	20.1	(0.44)	2.8	(3.8)	110	(0.0)	28	(0.1)	-0.87	(0.16)
	3	19.0	(0.46)	2.3	(4.7)	117	(0.0)	36	(0.1)	-0.38	(0.09)
	4	19.3	(0.80)	-0.5	(2.8)	112	(0.0)	29	(0.0)	-0.22	(0.11)
	5	23.3	(0.47)	-2.8	(3.9)	109	(0.0)	25	(0.1)	-0.16	(0.06)
	6	21.0	(0.35)	-0.3	(2.5)	107	(0.0)	28	(0.1)	-0.23	(0.25)
	7	18.4	(0.62)	3.1	(3.8)	121	(0.0)	14	(0.1)	-0.04	(0.08)
	8	20.4	(0.82)	-3.0	(3.5)	114	(0.0)	37	(0.1)	-0.21	(0.12)
	9	21.6	(0.62)	-4.8	(3.8)	110	(0.0)	24	(0.0)	-0.44	(0.05)
	10	19.7	(0.59)	5.5	(5.8)	119	(0.0)	18	(0.1)	-0.35	(0.14)
	11	22.3	(0.67)	-6.0	(3.5)	115	(0.0)	28	(0.1)	-0.47	(0.05)
	12	20.2	(0.50)	0.0	(3.6)	107	(0.0)	31	(0.1)	-0.58	(0.09)
	13	21.2	(0.39)	-0.2	(3.0)	115	(0.0)	33	(0.1)	0.07	(0.11)
	14	20.5	(0.49)	-1.0	(3.0)	111	(0.0)	21	(0.1)	-0.26	(0.12)
	15	22.7	(0.35)	-2.5	(5.7)	107	(0.0)	31	(0.1)	-0.17	(0.18)
	16	21.4	(0.50)	1.0	(1.4)	113	(0.0)	17	(0.0)	-0.40	(0.09)
	17	23.2	(0.23)	-5.1	(2.8)	112	(0.0)	34	(0.1)	-0.42	(0.13)
	18	21.9	(0.54)	1.3	(1.9)	111	(0.0)	33	(0.0)	-0.35	(0.07)
	19	23.2	(0.42)	-3.9	(3.4)	109	(0.0)	32	(0.1)	-0.36	(0.10)
	20	20.7	(0.46)	-3.5	(2.8)	116	(0.0)	38	(0.1)	-0.39	(0.14)
Overall mean		21.14	(0.51)	-2.45	(3.72)	111.4	(0.0)	29.7	(0.1)	-0.355	(0.12)
	s	1.41	(0.18)	3.55	(1.09)	4.2	(0.0)	7.0	(0.0)	0.220	(0.06)

Note: RelSp, release speed; RelAng, release angle; RelHt% & RelDist%, release height and distance respectively as a percentage of stature; FFPos, y position of the left heel with respect to the bowling crease.

Eighteen of the 20 bowlers released the ball at a more downward angle on the 16 yard pitch (Table 4.1). In fact the median release angles of 19 bowlers were below the horizontal on the 16 yard pitch (range -10.5 to 0.5°), compared with only 12 on 19 yards (range -6.0 to 5.5°). Hence, at -4.2° the group mean release angle was 3.4°, 95% CI [2.0, 4.8] further below the horizontal on 16 yards than on 19 yards (at -0.7°), with a large effect size of 1.08 (Table 4.2).

Table 4.2. Means, differences between means, confidence intervals and effect sizes for ball release parameters and their variability.

	16 yd (mean ± s)	19 yd (mean ± s)	Difference	95% CI on Difference	Effect Size
RelSp ($m.s^{-1}$)	21.2 ± 1.43	21.1 ± 1.42	0.13	-0.06, 0.32	0.09
RelSp variability	0.50 ± 0.19	0.53 ± 0.17	-0.03	-0.11, 0.05	0.18
RelAng (°)	-4.2 ± 3.1	-0.7 ± 3.2	-3.4	-4.8, -2.0	1.08
RelAng variability	3.85 ± 0.94	3.59 ± 1.23	0.26	-0.3, 0.8	0.21
RelHt% (% stature)	110 ± 4.3	112 ± 4.9	-1.8	-2.4, -1.3	0.46
RelHt% variability	0.0 ± 0.0	0.0 ± 0.0	0.0	-0.0, 0.0	0.21
RelDist% (% stature)	31 ± 6.9	28 ± 6.9	3.2	1.4, 5.0	0.47
RelDist% variability	0.1 ± 0.0	0.1 ± 0.0	0.0	-0.0, 0.0	0.43
FFPos (m)	-0.36 ± 0.22	-0.35 ± 0.22	-0.01	-0.0, 0.0	0.03
FFPos variability	0.13 ± 0.06	0.12 ± 0.05	0.01	-0.02, 0.05	0.30

Note: RelSp, release speed; RelAng, release angle; RelHt% & RelDist%, release height and distance respectively as a percentage of stature; FFPos, y position of the left heel with respect to the bowling crease.

The average Release Height % was lower and average Release Distance % greater on the shorter pitch, both small effects (equivalent to 0.03 m lower and 0.05 m further forward).

Placement of the front foot at the point of delivery was essentially unchanged between the two pitch lengths, the heel being approximately 0.35 m behind the bowling crease. Of the 20 bowlers only three bowled one or more No balls (where no part of the front foot is behind the back edge of the bowling crease, i.e. the front foot position was positive). Between those three, only 12 No balls were bowled in total: 2.5% of the 480 balls recorded. Just one bowler's median front foot position was in front of the crease, by 0.09 m on the 16 yard pitch and 0.07 m on 19 yards.

Group mean variability was not substantially different between pitch lengths for any of the release parameters.

4.4 DISCUSSION

This study quantified the impact of altering the pitch length on the ball release position, speed and angle of deliveries by a group of 20 junior seam bowlers. The only large difference found was in the initial angle of projection of the ball (release angle) which was 3.4° lower on the 16 yard pitch compared with the 19 yard pitch.

The ball release heights as a percentage of stature reported here are comparable to the values in the literature (e.g. Bartlett, Stockill, Elliott and Burnett, 1996; Salter, Sinclair and Portus, 2007; Spratford, Keneally-Dabrowski, Byrne, Hicks and Portus, 2016; Worthington, 2010), while release distance usually goes unreported, or is measured from a fixed point and not normalized with respect to stature (Cork et al., 2012). Ball release height and release distance are dependent on and limited by both physique and technique, furthermore the nature of the bowling action dictates that an increase in release distance tends to accompany a decrease in release height, and vice versa, as found in this study. Release height variations of the magnitudes found in bowling have a very limited influence on the time of flight and consequently on the range of the ball in flight, as illustrated by Dupuy et al. (2000) for an underarm throwing task. At the typical release speeds and angles of bowlers in this study, the

1.8 percentage point difference in Release Height % makes a difference of about 0.1 m to the range. So the influence of changes to release height and release distance on the horizontal distance from the heel of the front foot to the point where the ball bounces are individually small, and in combination negligible.

The minimal change in front foot position between pitch lengths gives no indication that the players tried to compensate for the pitch length difference by adjusting their run ups, for example by bowling from in front of the bowling crease ("No balling") on the 19 yard pitch, or further behind the crease on 16 yards. The bowlers were given no specific instructions about from where they should bowl but, with one exception, usually bowled with at least part of their front foot behind the bowling crease, in accordance with the No ball law (Law 21; MCC, 2017a). In the exceptional case, although most of his deliveries were slight No balls, his foot placement was very similar on both pitch lengths, again indicating that he was not using this as a means to adapt to the change of pitch length.

Ball release speeds in this study were slightly faster on average than the 20.1 $m.s^{-1}$ reported by Elliott et al. (2005) for players of the same age bowling as fast as they could, possibly indicating a slightly higher average standard of player in the current study. Elliott et al. (2005) stated that on a shorter pitch bowlers "do not have to develop the same ball speed to attain a 'good length'" (p. 662), which is clearly true mechanically. Nevertheless in their study of bowlers from three age groups (under-11, 13 and 15) who were asked to complete a target bowling task on 16, 18 and 20.12 m pitches, they found no significant differences in ball release speed between pitch lengths for any of their age groups. Their players were specifically asked to bowl as fast as they could, which might have prevented them from using release speed as a means of adjusting for the pitch length alteration. Here players were simply asked to bowl at their usual pace, but again no difference between release speeds on the two different pitch lengths was found. Phillips, Portus, Davids and Renshaw (2012) studied three groups of different standards of bowler (national and emerging adults, and national or regional representative standard older juniors) and similarly found no differences between bowling speeds for each group when they were asked to bowl short, good and full length deliveries "at match intensity" (speed).

Assuming negligible aerodynamic influences, for a ball projected horizontally from the average release height found in this study, the 0.13 $m.s^{-1}$ speed difference found between pitch lengths would make less than a 0.08 m change to the horizontal range from release to bounce. By contrast, releasing the ball 3.4° below horizontal at the same speed would reduce the range by in excess of 2.4 m, nearly 88% of the pitch length change in this study. The implication is that the ball release angle is the critical parameter for bowlers to control.

Artificial turf, as used in this study, typically has a higher bounce than natural turf (Ball and Hrysomallis, 2012) which will influence the bowlers' judgements of length. However this study looked at intra-individual changes on one surface therefore the influence of the surface on the bowlers' adaptations is limited and extrapolating the findings to turf pitches is reasonable.

Individual variability has not often been reported in cricket bowling studies but some comparisons are possible. The mean individual release speed standard deviation of 0.51 $m.s^{-1}$ at an average bowling speed of 21.1 $m.s^{-1}$ here corresponds to a coefficient of variation of approximately 2.4%, which is very similar to the 2.5% calculated from the data Justham et al. (2008) reported for eight emerging national adults. It is also similar to the 2.3% calculated from Phillips, Portus, Davids, Brown and Renshaw (2010) for elite juniors, but greater than the 1.6% for their elite adults. Renshaw and Davids (2004) reported front foot placement variability (standard deviation) averaging 0.11 m for six professional medium to medium-fast paced bowlers, similar to the 0.12 m for the junior bowlers in this study. Individual standard deviations in release angle averaging 1.8° were found by Justham et al. (2008) for eight emerging national adults bowling at an average of 32.3 $m.s^{-1}$, just under half the 3.7° for the young bowlers analysed here. As discussed earlier, given the importance of the release angle to where the ball pitches and the effect of speed on this range, the reduced variability in release angle at the much higher release speeds elite bowlers achieve should come as no surprise.

It would have been possible to exclude No ball deliveries, balls bowled from too far behind the bowling crease, or balls bouncing outside of a prescribed range from the batting end stumps. However this would have increased the number of deliveries required of the young bowlers beyond the limits set down by the governing body (England and Wales Cricket Board, n.d.-b) and would have influenced the variability measures which were part of the investigation. Including all deliveries but using individual medians rather than the means was chosen as a compromise which also avoided any potential for experimenter bias.

The variability of the release parameters were similar on both pitch lengths although it had been anticipated that release speed and release angle in particular would be more variable on the longer pitch if the bowlers have to struggle to bowl a good length. However the bowlers in this study were of a high standard for their age, having demonstrated an ability to bowl on the 19 yard pitch in order to be selected as bowlers for their county squads or be rated as the best at their clubs. It might be more revealing to study bowlers of this standard bowling on a 22 yard (20.12 m) pitch to determine whether the *increased* distance resulted in more variability. Similarly, average club standard players bowling on a 16 yard pitch might achieve an improvement in consistency compared with bowling over 19 yards that was not apparent in county standard bowlers.

Compared with -0.7° on the 19 yard pitch, the mean release angle of -4.2° on 16 yards was closer to the -7° of emerging national bowlers (Cork et al., 2012; Justham et al., 2008; Worthington, 2010). Shortening the pitch does appear to be a means of encouraging young bowlers to bowl more like adults by projecting the ball at a more downward angle. However the release angle difference between elite bowlers and junior bowlers on a 16 yard pitch in this study might seem to suggest that the pitch should be shortened still further. For a number of reasons this might not be the case. Firstly, on both pitch lengths the young bowlers bowled on average 0.36 m behind the bowling crease and were therefore further from the batter's end than necessary. Bowling from closer to the crease would reduce the distance and theoretically lead to a steeper release angle if aiming to land the ball on the same spot. Secondly, in common with most elite pace bowlers, Worthington's 20 bowlers were very tall, mean height 1.88 ± 0.08 m and the median height percentile for the group was the 90th (Worthington, 2010), compared with the juniors in this study for whom the median height percentile for their age was the 58th. Although the plausible range of *individual* differences in release height has little effect on the ball flight distance, the release height difference between very tall and average height players would be expected to have more of an influence; for a given speed of delivery, in order to bowl to the same point on the pitch, taller players need to release the ball at a steeper downward angle than shorter players.

For junior seam or pace bowlers to bowl exactly like very tall, elite bowlers may not be realistic, but it is clear from this study that even good bowlers for their age are not close to releasing the ball in a similar manner on a 19 yard pitch. These bowlers were also taller than average for their age (only four were below the 50th percentile), suggesting that the trend towards seam bowlers being tall starts at an early age, perhaps *because* the pitches they play on are relatively long. In fact on currently recommended pitch lengths, bowling like adults is probably an unrealistic expectation for all but the most physically mature and technically able for their age. If young players are to develop techniques more like the best bowlers the pitch length needs more closely to match their physical capabilities. Elliott et al. (2005) pointed out that a shorter pitch for juniors means “performance requirements are much easier to achieve, so players are more likely to focus on the correct execution of their action” (p. 662). As a consequence success and enjoyment should follow, in contrast to the current situation where the difficulty of bowling the required distance may put some children off playing cricket entirely.

The shorter pitch length in this study encouraged the bowlers to bowl “into the pitch” more which will enable them to get more movement and bounce off the surface, but further research is required to determine *optimum* pitch lengths for junior age groups. A shorter pitch length may mean that a genuine short delivery, a “bouncer”, becomes a possibility for the quicker young bowlers, which also raises the demands placed on batters as an issue requiring consideration.

4.5 CONCLUSIONS

In response to an alteration in pitch length, junior bowlers adjusted the angle at which they projected the ball without substantially changing ball speed or release position. The variability in ball release parameters was comparable to other studies, with the exception of the ball release angle which was less consistent than for elite adults, and pitch length did not affect variability. On the shorter pitch players bowled the ball with a more downward trajectory, approaching that of elite adult players. This should lead to greater success and enjoyment, as well as facilitating further technique improvements.

CHAPTER 5
A SHORTER CRICKET PITCH IMPROVES DECISION-MAKING BY JUNIOR BATTERS

5.1 INTRODUCTION

In cricket, batters have an array of shots from which to choose in order to combat the variety of pace, seam, bounce, swing and spin with which the bowlers may try to defeat them. The most basic decision is whether to play forwards or backwards based on where the ball bounces and learning to "pick the length" is fundamental to batting. Woolmer, Noakes and Moffett (2008) said "being able to move forward and back correctly greatly increases the chances of success; therefore early and accurate judging of length becomes vital" (p. 96).

The decision about whether to play forward, that is move the foot nearest the bowler towards the ball, or play back, moving the other foot back towards the batter's stumps, depends on how far from the batter the ball is going to bounce (Bradman, 1958; Woolmer et al., 2008). If a delivery is going to bounce close enough to the batter, a "full ball", he or she will step towards it and attempt to strike it before or soon after it bounces, making what is known as a *front foot* shot. A ball landing further from the batter, a "short ball", will usually be played with a *back foot* shot.

Clearly the ball sometimes bounces at distances where the batter could reasonably play forward or back, or possibly is unsure which is the correct choice (Pinder, Davids and Renshaw, 2012). These deliveries were defined by Sir Donald Bradman as good length balls, "The type of delivery which has the striker in two minds as to whether he should play forward or back" (Bradman, 1958, p.97). This definition has been paraphrased many times and several have also specified a distance or range of distances from the batters' end stumps for this bounce point, in order to create this indecision for adult batters (summarised in Figure 5.1).

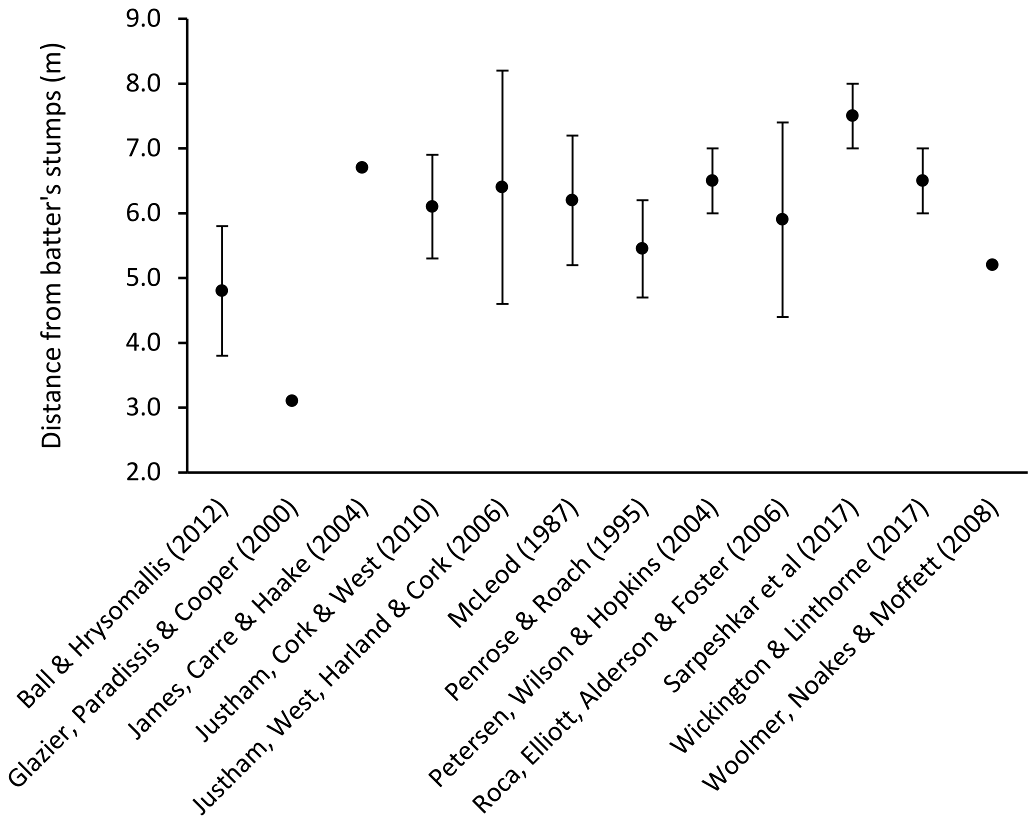

Figure 5.1. Good length estimates for adults (centre of region and range where specified).

Good length regions for adults appear to centre on a distance approximately 6 m from the batters' stumps (the median value from the studies in Figure 5.1 is 6.15 m) which corresponds with the distance at which Abernethy and Russell (1984) found a marked drop in response accuracy, compared with those bouncing shorter or fuller, by batters of all skill levels in a study where ball flight was occluded. Woolmer et al. (2008) however pointed out that the reach of the batter, pace and bounce of the pitch and match situation can all influence what is considered to be a good length, as do the trajectory differences between pace or seam and spin bowling. In fact McLeod (1987) proposed that a good length wasn't a fixed place but is "just less than 200 ms away from the batsman" (p. 59), which may be true but is unlikely to be useful advice from coach to bowler. The literature provides little guidance on where the good length region lies for junior age groups, although Pinder et al. (2012) used a scaling method based on batters' stature to calculate target regions for bowlers.

According to McLeod (1987) whether to play forward or back to a delivery is the first decision a batter must make. In junior cricket in particular, where deviation of the ball in flight or off the ground is less pronounced, judging the length is the fundamental decision for the batter. Skilled batters are thought to make this judgement on the basis of the early flight of the ball, cues picked up from the bowler's pre-delivery movements, and potentially using situational probability (Abernethy and Russell, 1984; Brenton et al., 2016; Müller et al., 2009, 2006; Müller and Abernethy, 2006; Weissensteiner et al., 2008). However, in under-11 club matches on current pitch lengths nearly one fifth of deliveries initially bounce a long way from the batter before going on to bounce again (sometimes more than once) before being within striking distance (Chapter 3). Batters often play forward to these short balls, contrary to the accepted method which would be to play on the back foot to short deliveries. This means that from a young age batters are learning inappropriate or confused decision making which they will have to correct as they mature. Not only is this inefficient, but it has the potential to be dangerous as players progress to bat against older, faster bowlers who can make a short ball bounce higher and where playing forward could lead to balls striking the batter on the upper body or head.

Looking at the influence of scaling sports equipment and playing areas on motor skill acquisition in children's sport Buszard, Reid, Masters and Farrow (2016) highlighted the need to "simplify skill performance whilst maintaining perception–action couplings akin to the adult game" (p. 829). In Chapter 3 it was shown that reducing the length of the pitch halved the number of balls bouncing twice or more in under-11 club cricket, so it was anticipated here that batting on a shorter pitch would improve the coupling between judging the length of the delivery and selecting the appropriate shot type. In particular it was expected that batters would be more likely to play back foot shots to short deliveries, in line with recommended technique (e.g. Woolmer et al., 2008). The apparent dominance of front foot shots to all deliveries meant it less likely that there would be an increase in the proportion of front foot shots to full deliveries.

Investigating this depended upon having an estimate of where the good length region lies for cricketers in this age group and therefore how far from the stumps a ball must bounce to be considered “short” or “full”. In this study the focus was on batting against seam/pace bowling as at the earliest ages of junior competitive cricket very few players spin the ball appreciably (although a small number at county level have begun to develop this bowling style). To determine what constituted a short or full delivery the front or back foot shot selection of top order under-10 county batters was used as an indicator of their judgement of length (Müller et al., 2009; Müller and Abernethy, 2006; Stevenson, Smeeton, Filby and Maxwell, 2015) when facing under-10 county seam bowlers. It was anticipated that there would be a range of ball bounce distances where these skilled batters did not overwhelmingly favour playing forward or backward, indicating the uncertainty which a good length ball induces.

The purpose of this study was therefore first to establish an “uncertainty” or good length region based upon which deliveries could be classified as “short”, “good” or “full” in under-10 and under-11 cricket. It could then be determined whether club and county batters played a higher proportion of back foot shots to short deliveries and front foot shots to full deliveries in matches played on a shorter pitch when compared to matches played on the currently recommended junior pitch lengths.

5.2 METHODS

5.2.1 MATCHES AND PARTICIPANTS

During an English junior cricket season six county under-10 boys and fourteen under-11 mixed club cricket matches were played on two different pitch lengths (Table 5.1).

Table 5.1. Match and player details.

	Pitch length (yards)	Number of matches	Number of teams	Number of players	Player ages (years; mean ± s)
Club	20	7	11	92	10.41 ± 0.98
Club	16	7	10	98	10.46 ± 0.95
County	19	3	5	61	10.08 ± 0.53
County	16	3	4	57	10.15 ± 0.50

Note: Seven club and two county teams played in more than one match (against different opponents) but rotated some players. Age groups based on age at midnight on preceding 31st August; player ages given at the start of the season. Girls were permitted to play in the club matches; only 12 girls played.

A Level Four county coach selected 16 yards (14.63 m) for the study, while 19 yards (17.37 m) and 20 yards (18.28 m) were the England and Wales Cricket Board recommendations in place for under-10s and under-11s respectively. Ethical approval was obtained from the university, and assent from the clubs, counties and players and informed consent from their parents was obtained.

Club matches were played using an 8-a-side pairs format in which each pair of batters batted for four, six ball overs and each fielder (except the wicket-keeper) bowled two or three overs in a 16 over innings. The county matches were 11-a-side limited overs format following the Laws of Cricket in effect at the time (MCC, 2015).

5.2.2 DATA COLLECTION AND CODING

A Panasonic DMC-FZ200 camera recorded HD MP4 video at 30 fps and shutter speed of 1/125th s throughout each innings from just outside of the boundary, mid-way along and perpendicular to the pitch. The lens was zoomed-in so that the field of view included the length of the pitch from wicket to wicket plus approximately one meter at either end.

From the videos, two experienced cricketers, one a level two coach and the other a cricket performance analyst, independently categorized each shot played as either front foot or back foot. Deliveries to which the batters played a shot but missed the ball were included, while deliveries which batters did not attempt to play were noted as such but omitted. Very occasionally there was no clear foot movement/shot type so those deliveries were also noted but excluded.

There was a 95.2% agreement between the two codings. Where disagreements occurred the lead investigator reviewed the video and decided whether there was a clear choice of shot or whether the shot should be excluded. In county matches the distinct front or back foot shots totalled 707 on the 16 yard and 1054 on the 19 yard pitches, and in club matches 1191 on 16 yard and 1188 on 20 yard pitches.

For each delivery the lead investigator also digitized the distance at which the ball bounced from the batter's stumps in conjunction with the shot type (front or back foot), all distances being scaled using the relevant pitch length. To determine the good length region for cricketers of this age, the shot selection by the top order batters (up to the first five batters where five or more were required to bat) against seam bowling in each of the county matches was analysed. This amounted to 29 batters playing 431 shots in the 16 yard matches and 29 batters playing 518 shots in the 19 yard matches.

5.2.3 DATA ANALYSIS

A Probit analysis (Finney, 1971) was conducted in SPSS to identify the distance from their stumps at which the top order county batters were equally likely to play front foot or back foot shots, in a similar way to Stevenson, Smeeton, Filby and Maxwell (2015). This generated a response probability model, with ball pitching distance as the independent variable and probability of back foot shot selection as the dependent variable.

Between 5 and 7 yards (4.6 to 6.4 m) from the stumps, the area anticipated to contain the transition from "more likely front foot" to "more likely back foot", responses were grouped into bins of a quarter of a yard (0.23 m; just over three ball diameters) and outside of this range half-yard bins were used. In each bin the probability of a back foot shot as a proportion of the total deliveries landing in that area was calculated. Very short and very full deliveries (more than 8.5 yards and less than 4 yards respectively) were excluded as very small numbers of observations render the modelling of the data unreliable.

Transition distance estimates with 95% confidence intervals were made for each pitch length separately and also with the data from the two pitch lengths combined. Based on the mean size of the good length regions for adults highlighted in Figure 5.1 (1.80 m/ 1.97 yards) and scaled in proportion to stature, good length regions 1.5 yards in length were determined with the transition distance estimates at their centre. Balls pitching further from the batters' stumps than the upper end of this range were deemed "short" and those closer to the stumps than the lower end were deemed "full".

Using these age-specific estimates for short, good and full length deliveries, the proportions (expressed per 100 deliveries) of each length in the county and club matches were compared between pitch lengths. Frequencies of front and back foot shots played by all batters to full and short balls respectively on each pitch length at both levels of competition were also calculated. Inter-pitch length differences between the proportions of back foot shots to short deliveries were calculated for county and club matches separately, as were the differences between proportions of front foot shots to full deliveries. Ninety-five percent confidence intervals around the differences between proportions were estimated according to the recommended method of Newcombe and Altman (2000) as implemented in ESCI (Exploratory Software for Confidence Intervals; Cumming, 2016). The differences between the proportions were the effect size estimates of interest and the magnitudes of these were related directly to the cricket environment: a difference equivalent to at least once per over (i.e. $\geq$ 1 in 6, or 16.7 per 100 deliveries) was defined as a large effect;

at least once in two overs (≥ 8.3 per 100 deliveries) as moderate; at least once in four overs (≥ 4.2 per 100 deliveries) as small; and anything less as trivial.

5.3 RESULTS

Pearson Goodness of Fit tests showed that the Probit models represented the 16 yard ($p=0.2$), 19 yard ($p=0.68$) and combined ($p=0.48$) foot movement data of the top order county batters well (Appendix E). The Probit estimates of the transition distance from predominantly front foot to predominantly back foot shots for the 16 yard and 19 yard data were 5.91 yards, 95% CI [5.69, 6.14] and 5.64 yards [5.43, 5.84] respectively. Cumming (2009) demonstrated that a 50% overlap of 95% confidence intervals equates to conservative estimate of $p=0.05$ for the difference between independent proportions; the 70% overlap of the confidence intervals here confirmed that these estimates were not significantly different (Figure 5.2). Furthermore the difference of just 0.27 yards (0.25 m) is less than four ball diameters, so a small difference in practical terms. Therefore the transition distance of 5.76 yards (5.27 m)

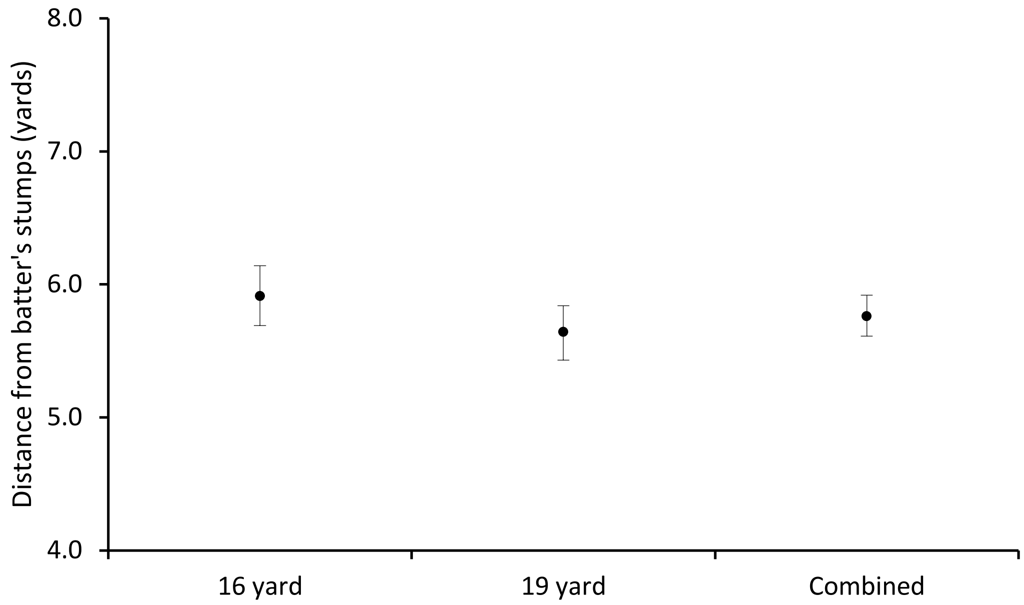

Figure 5.2. Probit estimates of the transition distances based on data from 16 yard and 19 yard pitches, and the estimate from the combined data. Error bars are 95% confidence intervals.

calculated using the combined data was taken to be the middle of the good length or uncertainty region. A "full" delivery was then defined as one pitching less than 5.0 yards (4.57 m) from the batters' stumps and a "short" delivery as one pitching more than 6.5 yards (5.94 m) from them. Inspection of the Probit model output showed that 5 yards coincided with the length at which batters would be expected to play forward 70% of the time (i.e. back 30%) and 6.5 yards coincided with expecting batters to play back 70% of the time (Figure 5.3).

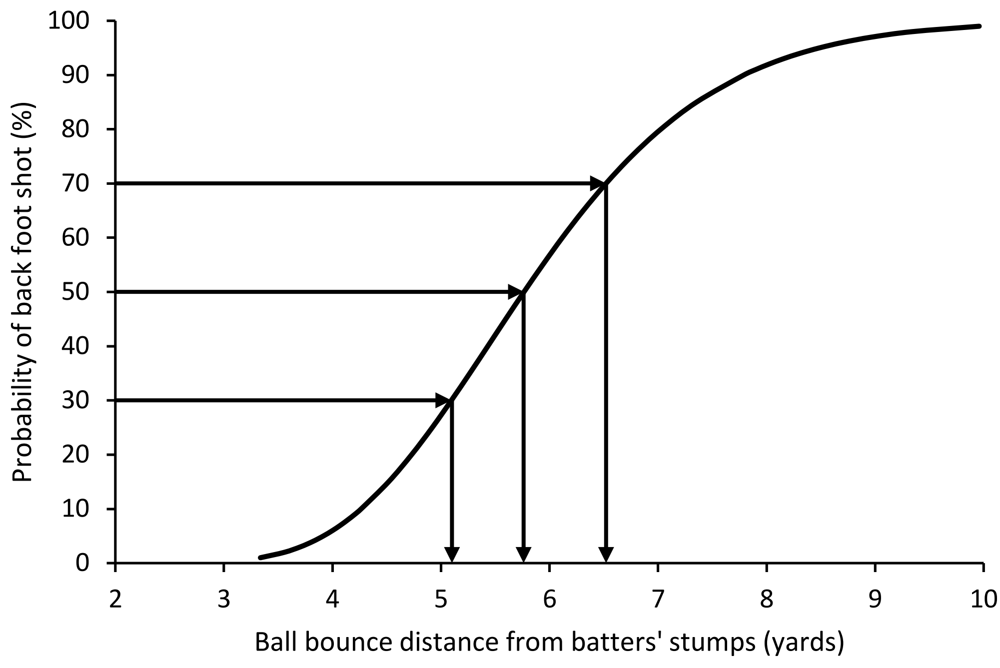

Figure 5.3. Probit model curve of back foot shot probability in relation to ball bounce distance from the batter's stumps. Distances corresponding to 30%, 50% and 70% probabilities highlighted.

The proportion of short deliveries on the 16 yard pitches was clearly lower than on the longer pitches (Table 5.2), a moderate difference of 8 per hundred deliveries, 95% CI [4.2, 12.2], in county matches and a large difference of 21 per 100 deliveries [17.8, 24.8], in club matches. On the 16 yard pitches the proportion of short deliveries was similar in both club and county matches, while in club matches there were nearly 20 more full deliveries per hundred [15.5, 23.4]. Other differences were less than 4.2 per hundred deliveries and as such of no practical importance (Figure 5.4).

Table 5.2. The proportions of full toss, full, good and short length deliveries (per 100 deliveries) for each match type and pitch length, and the differences between these proportions.

	Full toss	Full	Good	Short
County 19	5.5	43.6	22.6	28.4
County 16	6.8	47.7	25.5	20.1
Difference	1.3	4.1	2.9	-8.3*
Club 20	3.5	36.7	21.1	38.6
Club 16	7.6	56.2	19.0	17.3
Difference	4.0	19.5**	-2.2	-21.3**

Note: ** = large effect size; * = moderate effect size. Positive difference indicates a higher proportion in the short pitch matches.

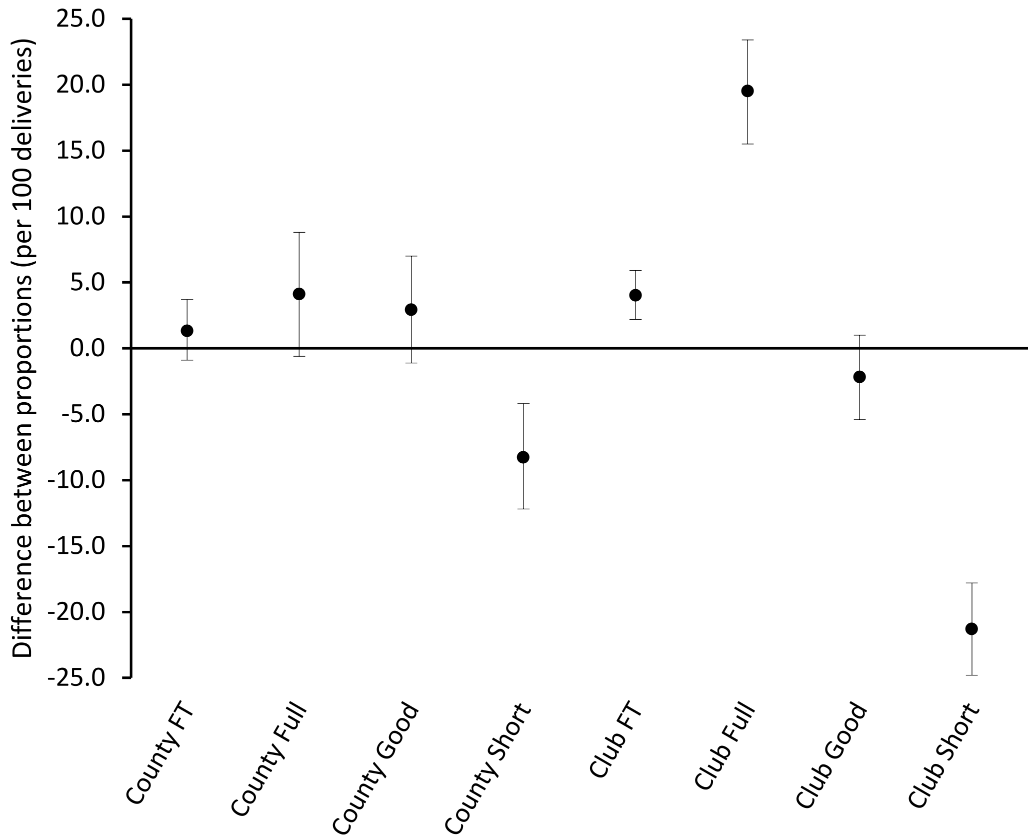

Figure 5.4. Differences between proportions of full toss (FT), full, good length and short deliveries for county and club matches. Error bars are 95% confidence intervals.

Although the proportion of short balls was lower on 16 yard pitches, both county and club matches saw a greater proportion of back foot shots to short deliveries (Figure 5.5). In the county matches it was 7% higher, 75 per hundred deliveries compared with 70, a moderate effect of 5, [-4.1, 13.5], although the 95% confidence interval includes the possibility of no difference. In the club matches the back foot shots to short balls proportion on short pitches was more than double that on the longer pitches, 19 compared with 9, a large effect of 10, [4.6, 16.5]. The proportion of front foot shots to full balls was greater in 16 yard pitch county matches, a moderate difference of 6, [2.3, 8.7], 97 compared with 92 (6% higher). In club matches the difference was negligible.

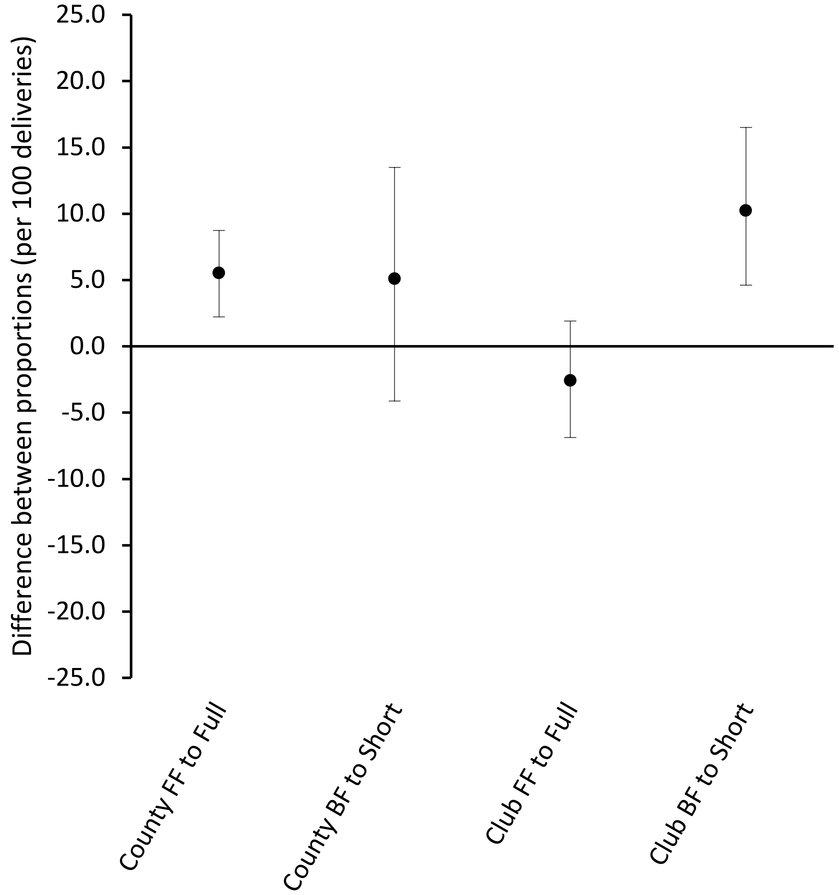

Figure 5.5. Differences between proportions of front foot (FF) shots to full deliveries and back foot (BF) shots to short deliveries for county and club matches. Error bars are 95% confidence intervals.

5.4 DISCUSSION

Successful batting depends critically on establishing an appropriate link between the batter's perception of where the cricket ball will bounce (the delivery length) and gross foot movement, forward or backward. In order to make meaningful inferences about shot decisions the concepts of short, good and full length deliveries were defined for the age of the players. The Probit analysis enabled a 1.5 yard (1.4 m) "good length region" from 5.0 to 6.5 yards (4.6 to 5.9 m) from the batters' stumps to be calculated. Within this region the batters were estimated to be at best 70% sure whether to play front or back foot shots, emphasising the uncertainty that this length of delivery induces. This area is effectively a meta-stable region as described by Pinder, Davids and Renshaw (2012), though for their "junior" batters (aged 16.3 ± 0.3 years and almost of average adult stature), their region was 6.5 to 7.5 m from the batters' stumps. They specified their region *a priori* but subsequently found a 48% forward, 52% backward choice of movement responses when balls pitched between these lengths. Scaled just in proportion to average height, the centre of their meta-stable region would lie at 5.5 m (6.0 yards) for a ten year old, in reasonable agreement with the 5.76 yards determined here.

On currently recommended pitch lengths young players often play forward to balls to which, based solely on the ball bounce location, they should play back. This study found that playing on a shorter pitch increased the likelihood that under-10 and under-11 county and club cricketers would play back to short deliveries. The higher proportion of back foot shots played to short balls on short pitches is an important difference, particularly in club matches where it was more than double that on the longer pitches. Recognising short pitched deliveries and moving onto the back foot is characteristic of skilled batters (Woolmer et al., 2008) and shorter pitches encouraged this in the young club players. However it is interesting to consider why, at only 19 back foot shots per 100 short deliveries compared with 75 per hundred in county matches, the proportion wasn't higher.

Firstly, playing forward to a short ball is not necessarily the wrong choice if, as is quite common in the younger club age groups, the bowling is slow and the bounce of the pitch is low. Secondly, there may be a considerable response bias towards playing front foot shots. Pinder et al. (2012) noted that batting against full deliveries is "practiced almost exclusively in the developmental stages of cricket batting" (p. 439), so young club players become more comfortable with the front foot drive, which is reasonably effective even against short deliveries if the ball isn't bouncing very high or on the traditionally longer pitches where the ball may bounce twice or more before reaching the batter. On a shorter pitch, front foot shots to short balls are less effective, making players more likely to learn back foot skills implicitly and to be coached them explicitly. County players have more experience of playing against quicker bowling on better prepared pitches and have also received coaching which is more likely to have included playing back foot shots hence the higher proportions of back foot shots in county matches on both pitch lengths. A third reason may be that batters expect a full delivery if they are unsure of the length. Visual occlusion studies of batting have found that even skilled adult batters favour a front foot shot if they are uncertain about the length of the delivery (Abernethy and Russell, 1984; McLeod, 1987; Müller and Abernethy, 2006; Müller et al., 2006). Playing on appropriately scaled pitches throughout their development should mean that young players in future exhibit less bias towards front foot shots.

Müller and Abernethy (2012) set out the three, sequential sources of information aiding a batter's decision making in striking sports: expectations and situational probabilities; pre-release information based on the bowler's kinematics; and observation of the early flight. It is unlikely that expectation and situational probability are used by young batters even on shorter pitches, not least because the bowlers themselves are unlikely to have the skill or tactical knowledge to bowl to a particular plan. Similarly, considering young tennis players Farrow and Reid (2012) suggested that "situational probability information may not exist or at best is extremely inconsistent and hence unable to be relied upon to drive anticipatory performance" (p. 372).

Several studies of cricket and other interception sports have found that experts are able to utilize cues from opponents' pre-delivery or shot preparation kinematics in order to select and organize appropriate shot responses (e.g. Abernethy, 1990; Abernethy and Russell, 1984, 1987; Brenton, Müller and Mansingh, 2016; Müller et al., 2009, 2006; Penrose and Roach, 1995; Shim, Carlton, Chow and Chae, 2005). However Farrow and Reid (2012), Müller and Abernethy (2012) and Weissensteiner, Abernethy, Farrow and Müller (2008) noted that the temporal demands at junior and lower skilled levels are unlikely to require players to use anticipation in order to succeed. Indeed ten and eleven year old batters rarely appear hurried on 19 or 20 yard pitches: the ball isn't moving quickly and has quite a long way to travel. Müller et al. (2006) found that skilled batters used pre-release information in their judgment of length against medium pace but not spin bowling and suggested that some flight information is critical when batting against spin. However it could be a case of the batters not risking an incorrect judgement when they have time to be more certain; in other words not committing to the shot too soon. This would agree with the speculation of Triolet, Benguigui, Le Runigo and Williams (2013) that tennis players are likely to use anticipation mainly when waiting longer would leave them insufficient time to respond successfully to their opponent's shot. Although it has been suggested that non-experts *cannot* use early information from an opponent's movement pattern to anticipate (Müller and Abernethy, 2012), in the case of junior batters on long pitches it is likely that they rarely need to.

A shorter pitch however adds to the time pressure on the batter even though the bowling isn't faster (see Chapter 4 and also Elliott, Plunkett and Alderson, 2005) that is to say the ball is in the hitting area for the same amount of time even though it arrives there sooner. This reduced time to choose the appropriate shot imposes a task constraint on the batters which will increase their need to attend more to the pre-delivery movements of the bowlers and should encourage the development of the anticipation skills that batters need in order to progress towards expertise (Penrose and Roach, 1995; Weissensteiner et al., 2008). Studies have also suggested that coincidence-anticipation skills are quite well developed by around the age of 11 (e.g. Benguigui and Ripoll, 1998; Dorfman, 1977; Kim, Nauhaus, Glazek, Young and Lin, 2013) which suggests that players of this age are ready to be challenged to develop these skills in the competitive environment and to establish the perception-action couplings required at older, more advanced levels of the game.

The 16 yard pitch length selected by a highly experienced coach is shorter than the 16 m (17.5 yard) pitch length recently proposed for under-11 cricket in Australia (Cricket Australia, 2017). Differences between playing conditions (e.g. artificial turf pitches are frequently used in Australia) are likely to be a factor in this difference, but further work is required to determine the optimal length of pitch for the age group.

The high ecological validity of the data in this study was at the expense of control of the participants and conditions, such that the number of deliveries faced by each batter in total and from a given bowler, as well as the pitch surface itself, could not be regulated. The high volume of data both in terms of deliveries faced and the number and quality of participants compensated for the lack of control. It would be possible to conduct a study of footwork in a more controlled setting as Stevenson et al. (2015) did, however shot selection in a net or other artificial setting without a consequence for a false shot is never as realistic.

5.5 CONCLUSIONS

In club matches on 16 yard pitches the proportion of back foot shots to short deliveries was double that on the traditional, 20 yard pitches, even though the proportion of short balls was lower. This is an important change and the perception-action coupling between delivery length and shot selection for club players should become more like that currently exhibited at older ages and higher standards as a result. The difference in county matches was less pronounced but in the same direction. For both levels of play, the increased task demand of the shorter pitch should lead to improved anticipation skills, with batters attending more to bowlers' kinematics and their outcomes. As more leagues adopt shorter pitches coaches should place more emphasis on back foot shot techniques and increase the exposure of young batters to shorter, higher bouncing deliveries in practice. The empirically derived good length region determined in this study, where batters are least certain whether to play forward or back, provides valuable information to coaches and young bowlers in particular.

CHAPTER 6
SCALING THE PITCH TO FIT THE PLAYERS

6.1 INTRODUCTION

The current England and Wales Cricket Board pitch length recommendations for junior cricket are disproportionately long: In the simplest terms, the 20 yard (18.29 m) long under-11 pitch is 12.8 times the height of the average 11 year old, equivalent to requiring adults to play on a 24.9 yard (22.78 m) pitch, 13% longer than the traditional 22 yards (20.12 m). While many sports reduce the dimensions of the playing area for junior age groups (for example tennis, soccer, baseball, field hockey), Reid, Buszard and Farrow (2018) commented that most youth sport modification guidelines "come without any supporting empirical evidence" and "are a blend of educated guesses and practical design thinking." (p. 1285). This "practical design" approach often (understandably) means adapting junior pitches or courts to coincide with existing markings, for example juniors playing across the width of a full-sized tennis court or hockey or soccer pitch. Reid et al. (2018) called on sport science and medicine professionals to direct more of their efforts to the subject of modified sports for juniors.

There is increasing evidence in support of scaling the playing environment, and equipment, to enhance junior sport and produce something more closely comparable to the adult version (Burton, Gillham, et al., 2011; Buszard et al., 2016). However the method of scaling the playing space has received little attention. Scaling on the basis of relative height is superficially appealing, but there is always the question of who should form the reference group? Elite adults in many sports tend to be taller than average and have been getting taller faster than the general population (Norton and Olds, 2001), while the playing area dimensions were specified many years ago when people were shorter (Cole, 2003). In many sports some account of the physical capabilities of the players, rather than just their size would seem appropriate. For example Chase, Ewing, Lirgg and George (1994) studied basketball shooting by nine to twelve year olds and found height not to be strongly related to shooting performance, but speculated that strength may be important, particularly for girls. Timmerman et al. (2015) used the time between successive groundstrokes in junior and elite adult tennis to derive a scale factor for court size and net height, thereby incorporating more than simply the stature of the players.

In Chapter 3, where a shorter pitch length was estimated by a high-level coach, it was shown that outcomes were improved when under-10s and under-11s played cricket on the shorter pitch and in Chapter 4 it was shown that shortening the pitch encouraged top bowlers in those age groups to release the ball with a more downward trajectory. On average they bowled standard deliveries at 0.7° below horizontal on 19 yards (17.37 m) compared to 4.2° below on 16 yards (14.63 m), much closer to the 7° below horizontal found for elite pace bowlers on standard pitches (Cork et al., 2012; Justham et al., 2008; Worthington, 2010). Bowling on pitches which are disproportionately long, requires young players to change the way they release the ball as they "grow into" the pitch length, something also noted by Whiteside, Elliott, Lay and Reid (2013) in relation to tennis serving. Of more concern, it has also been suggested that it could put players at increased risk of injury (Elliott, Plunkett and Alderson, 2005).

It having been determined that a shorter pitch is beneficial, this study aimed to develop a method to scale the cricket pitch and with it to calculate the best pitch length for a specific age group. The starting proposition was that the pitch length for a given age group should enable good bowlers to bowl a good length delivery when bowling at a realistic speed and from a realistic release position, while releasing the ball with an initial trajectory close to that of top adult bowlers. The long-standing definition of a "good length" as being the region where batters are least certain whether to play a front or back foot shot was used (Bradman, 1958). These factors were incorporated into a model which was used to calculate a new pitch length for age group players and also to evaluate the influence of input parameters on the ball flight distance.

6.2 METHODS

6.2.1 THE MODEL

The length of the pitch was divided into three horizontal components: Release Distance, Flight Distance and the good length distance (Figure 6.1):

Release Distance: from the bowler's end stumps to the ball position at release. The heel of the bowler's front foot was assumed to be at the back edge of the bowling crease, 1.22 m from the stumps, in accordance with the Laws of Cricket (MCC, 2017a) and the ball was said to be released ahead of the heel by a proportion of stature.

Flight Distance: the horizontal distance from the point of release to the bounce point, determined by the initial conditions of ball release height, speed and angle, and as such the component over which bowlers have most control. Simulations were conducted neglecting air resistance, using equations of constant acceleration, and also including air resistance. In the latter case a drag force, $F_d = \frac{1}{2}\rho A C_d v^2$, acting tangentially to the ball's motion, at velocity v, was included in addition to gravity, and Euler's Method (with a time step of 10^{-4} s) was used to arrive at numerical solutions. Air density, ρ, was taken to be 1.225 kg.m^{-3}; A, the cross-sectional area of

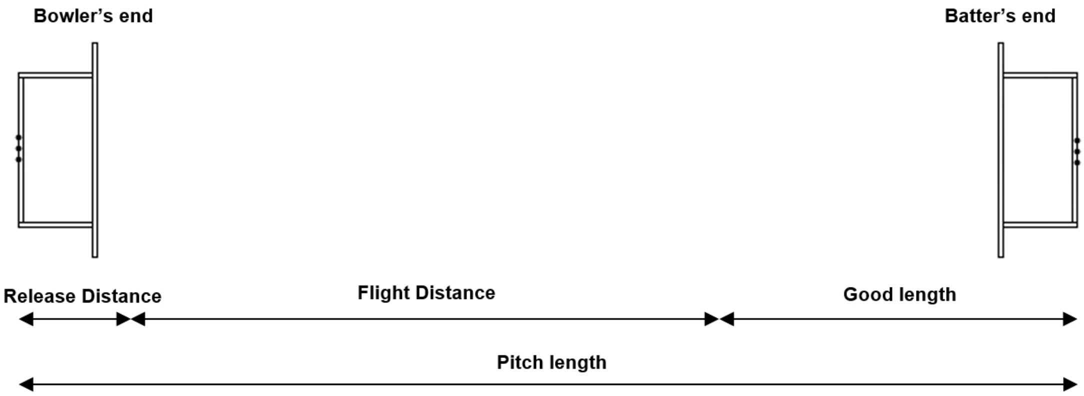

Figure 6.1. The three components of the pitch length.

a junior cricket ball is 3.6 x 10^{-3} m^2 and 4.07 x 10^{-3} m^2 for a senior ball; C_d, the drag coefficient has been found to be approximately 0.5 for a senior cricket ball at speeds between 20 and 34 $m.s^{-1}$ and at typical seam bowling seam angles (Sayers and Hill, 1999).

Good length: from the bounce point to the batter's stumps.

6.2.2 MODEL INPUTS

In Chapter 4 ball release data for age group bowlers was gathered using an 18 camera Vicon Motion Analysis System operating at 300 Hz. Twenty male, right-arm county or top club seam bowlers (average age 10.8 ± 0.63 years; height 1.46 ± 0.058 m) each bowled 12 standard deliveries at their usual pace on both a 19 yard (17.37 m) and a 16 yard (14.63 m) pitch at an indoor practice facility, with a leather, four-piece, 135 g junior ball.

The mean bowling speed of these players was 21.14 ± 1.41 $m.s^{-1}$ and the mean intra-individual variability in release speed and projection angle was 0.51 ± 0.18 $m.s^{-1}$ and 3.72° ± 1.09 respectively. Release height averaged 111% ± 4 of stature and balls were released ahead of the heel of the front foot on average by 30% ± 7 of stature; intra-individual variability on these measures was negligible. Combining these percentages with the average height of an 11 year old UK male being 1.43 m (Royal College of Paediatric and Child Health, 2012) gave a ball release 0.43 m in front of and 1.59 m above the front heel for the simulations. Ball radius was accounted for in the release height for the simulations.

For standard ("stock") deliveries elite adult pace bowlers have been found to project the ball at around 7° below horizontal and at speeds around 35 $m.s^{-1}$ (e.g. Bartlett et al., 1996; Cork et al., 2012; Justham et al., 2008; King, Worthington and Ranson, 2016; Worthington, 2010). However elite pace bowlers are generally tall: of the 20 emerging male national pace bowlers studied by (Worthington, 2010), 12 were taller than 90th centile and only three less than 70th centile. To compensate for this skewed distribution, the model was used to estimate the projection angle necessary for an *average* height adult (1.78 m; Moody, 2013) to bowl a good length on a 20.12 m (22 yard) pitch, releasing the ball at a speed of 35 $m.s^{-1}$ from a typical release position (using the proportions above). The good length distance for this simulation was 6.15 m (6.73 yards), while for junior simulations it was taken to be 5.27 m (5.76 yards), these distances being the centres of the good length regions estimated in Chapter 5 based on a literature survey and analysis of 10 year old top order county batters respectively. The adjusted projection angle was then used when calculating a pitch length for average height juniors.

6.2.3 MODEL APPLICATION AND EVALUATION

Pitch length calculations were made using the junior and senior input data, both with and without drag, and the percentage differences in the Flight Distance and overall pitch length were calculated.

To quantify the temporal challenge to a batter on a given pitch length, the time from the point of ball release to reaching the batter at the crease was calculated assuming a non-bouncing delivery (full toss) was bowled. Mean (21.14 $m.s^{-1}$) and fastest individual median (23.9 $m.s^{-1}$) ball speeds from Chapter 4 and a typical adult ball speed of 35 $m.s^{-1}$ were used, and allowance for differences in bowler stature and therefore release position was made. Air resistance was neglected.

As part of the junior bowler data collection reported in Chapter 4, ball bounce locations for deliveries by four bowlers were recorded at 200 Hz using a Panasonic DMC-FZ200 camera positioned perpendicular to the plane of the ball flight and focused on the region in which balls were expected to bounce. Calibration lines on the floor along a region 4 m long and 1.5 m wide enabled ball bounce positions to be determined with respect to the bowler's end stumps. Sixty deliveries which landed within the calibrated area were compared with bounce locations determined from the model given actual ball release position, speed and angle.

The sensitivity of the pitch length estimate to ball release speed, release angle and release height percentage was evaluated by varying each in turn while fixing the others. Release speed and angle were adjusted by the mean variability for the junior bowlers, 0.5 $m.s^{-1}$ and 3.7° respectively (Chapter 4), but intra-individual variability in release height percentage was negligible, therefore this was varied by the inter-bowler variability of 4% (equivalent to 0.057 m for an average height 11 year old boy).

The range of ball release speeds and projection angles that could be bowled while still bouncing the ball within the good length region on both a 19 yard pitch and the newly calculated pitch length were determined. Release height and distance from the front heel were fixed at 111% and 30% of mean stature for an 11 year old male respectively as before. Projecting the ball at an angle that would hit the centre of the good length region (5.76 yd/5.27 m from the batters' stumps) for balls bowled at 21.14 $m.s^{-1}$ on each pitch length, the release speeds which would land the ball 0.75 yards shorter and fuller (the limits of the good length region defined in Chapter 5) were found. In a similar way with the ball speed fixed of 21.14 $m.s^{-1}$, the ball projection angles necessary to hit the limits of the good length region were calculated.

The relationships between Flight Distance and both release speed and projection angle were explored by plotting Flight Distance against each parameter in turn over a range of reasonable values for the age group (speeds between 18 and 25 $m.s^{-1}$ and angles from +3° to -10°, as reported in Chapter 4). Least squares fits to the data then enabled the gradients of the curves to be found at selected release speeds and angles.

6.3 RESULTS

The ball projection angle necessary for an average height adult to bowl a good length on a 20.12 m pitch was calculated to be -6.2° (i.e. below horizontal) when air resistance was neglected and -6.0° when it was included. Flight Distance estimates for the average junior's deliveries varied by less than 1.4% with and without air resistance at these angles. Furthermore, comparing the 60 measured ball bounce locations with those determined when modelling the flight without air resistance resulted in a mean discrepancy of 0.02 ± 0.21 m (Appendix F). With a ball projection angle of -6.2° the pitch length calculated was 14.83 m (16.22 yards) neglecting and 14.72 m (16.10 yards) including air resistance, less than 1% difference.

The time from ball release to reaching the batter's crease, often called "transit time" (e.g. Justham, West, Harland and Cork, 2006; Penrose and Roach, 1995) for full tosses bowled at typical under-11 bowling speeds are much closer to the equivalent time for an adult bowling on a full length pitch on the newly calculated pitch length than the current 20 yard recommendation (Table 6.1).

Table 6.1. Time from ball release to the batter's crease for full tosses bowled on different pitch lengths and at different speeds.

Bowler	Pitch length (yd/m)	Ball speed ($m.s^{-1}$)	Transit time (ms)	Time difference (%)
Adult	22/20.12	35	490	-
Under-11	20/18.29	21.14	729	+49
Under-11	20/18.29	23.9	645	+32
Under-11	16.22/14.83	21.14	566	+16
Under-11	16.22/14.83	23.9	500	+2

Note: 20 yards is the currently recommended under-11 pitch length; 16.22 yards is the model derived pitch length; 21.14 $m.s^{-1}$ is an average under-11 bowling speed and 23.9 $m.s^{-1}$ is representative of the fastest individual, both reported in Chapter 4.

The pitch length estimate was found to be sensitive to the typical variability in the projection angle displayed by young players, but insensitive to their variability in release speed and release height as a percentage of stature (Table 6.2).

For 19 yard and 16.2 yard pitch lengths the ranges of ball release speeds which would still result in balls bouncing within the good length region were 3.18 $m.s^{-1}$ and 5.97 $m.s^{-1}$ respectively and the projection angle ranges were 2.0° and 2.8°. Thus on the shorter pitch there is an 88% greater tolerance in speed and 40% greater tolerance in angle.

Table 6.2. Sensitivity of pitch length to input parameter perturbation.

Ball speed ($m.s^{-1}$)	Release height (%)	Projection angle (°)	Flight Distance (m)	Pitch length (m)	Pitch length difference (%)
21.14	111	-6.2	7.91	14.83	-
20.64	111	-6.2	7.79	14.71	-0.8
21.64	111	-6.2	8.02	14.94	+0.8
21.14	**107**	-6.2	7.70	14.62	-1.4
21.14	**115**	-6.2	8.11	15.03	+1.3
21.14	111	**-2.5**	10.06	16.98	+14.6
21.14	111	**-9.9**	6.32	13.23	-10.7

Note: Emboldened figures represent the typical variability in each input parameter.

Across the typical young bowlers' range of ball release speeds and projection angles, release speed is approximately linearly related to Flight Distance and has a limited influence on it. The gradient of the line is 0.23 s (metres per [metres per second]) for projection at an angle of -6.2° compared with 0.51 s at an angle of -0.7°, the mean angle found for this age group when bowling on a 19 yard pitch (Figure 6.2).

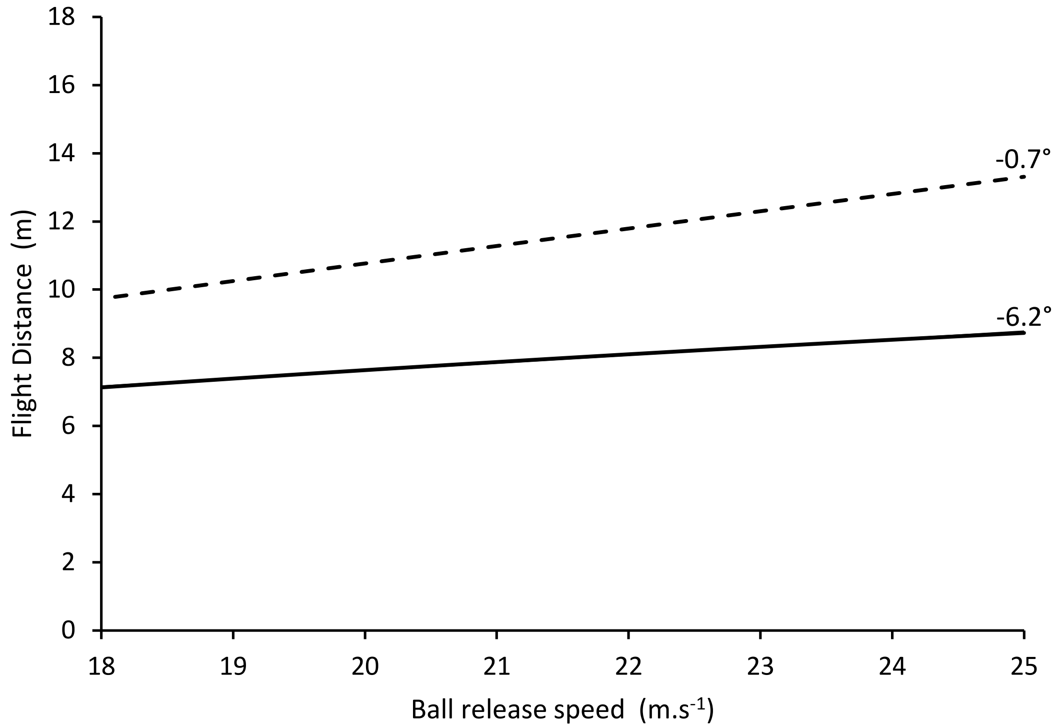

Figure 6.2. Flight distance over a typical range of ball release speeds when projection is at -0.7° and -6.2° and release height is 1.553 m (111% of average height minus ball radius).

For a given release speed, Flight Distance has an approximately quadratic relationship with projection angle over a typical range (Figure 6.3). Regardless of release speed, the gradient of the curve is shallower as the ball is projected further below the horizontal. At 21.14 $m.s^{-1}$ the gradient at -6.2° is 0.51 metres per degree, while at -0.7° is 0.76 metres per degree.

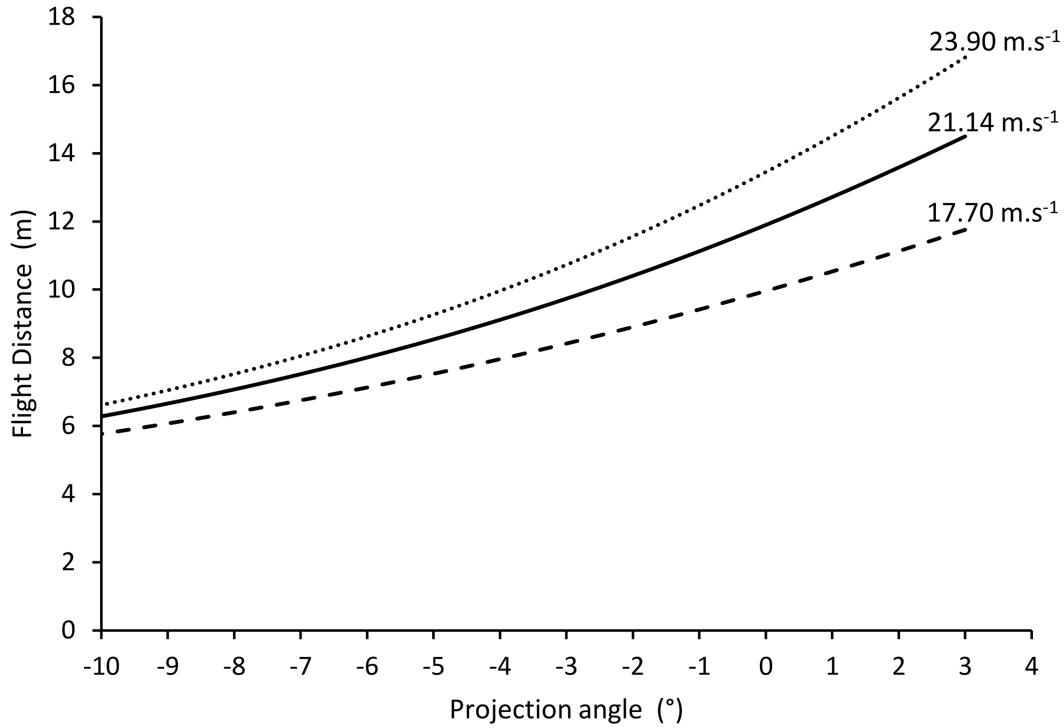

Figure 6.3. Flight distance over a typical range of ball projection angles at three release speeds (slowest, fastest and mean speeds from Chapter 4) with release height at 1.553 m (111% of average height minus ball radius).

6.4 DISCUSSION

The cricket pitch length was modelled to enable the calculation of an optimal length based on realistic characteristics of both the bowlers and batters within an age group. Inputs were the typical bowling speed and ball release position of the bowlers, and the distance from the batters' end stumps that the ball should bounce in order to produce the greatest indecision for batters when choosing whether to play a front or back foot shot. The flight of the ball from release to bounce was modelled with and without air resistance, using projection angles of -6.0° and -6.2° respectively, which were calculated to be representative of an elite-pace bowler of average adult height bowling a good length delivery.

The influence of air resistance was found to be negligible. Drag impedes the ball's horizontal motion but for balls projected below horizontal drag also increases the time before bounce occurs. Overall, including drag in the simulations showed it to reduce Flight Distance by less than 2% even at adult bowling speeds with a senior sized ball and the resulting pitch lengths for under-11s differed by less than 1%. The coefficient of drag used, 0.5, is typical for senior-sized cricket balls moving at less than the critical Reynolds number of approximately 1.5×10^5 (Mehta and Wood, 1980) which corresponds to over 31 $m.s^{-1}$; for a junior ball a lower drag coefficient could be justified. Although the Magnus force created by the backspin imparted to the ball was not included in the model it has been shown to have a smaller influence than drag in cricket bowling (Sayers and Hill, 1999) and any influence it does have keeps the ball in the air for longer, further counteracting the potential Flight Distance reduction by the horizontal drag component. At high bowling speeds and backspin rates it has been suggested that it could actually increase the flight distance (Robinson and Robinson, 2015). Therefore it was reasonable to conclude that aerodynamic factors could be ignored when estimating the Flight Distance of the ball at the speeds and over the distances involved in bowling.

The model calculated pitch length of 16.22 yards (14.83 m) is 19% shorter than the current recommendation of 20 yards (18.29 m) for under-11s. Scaling a full length pitch simply based on the ratio of the average height of an 11 year old to that of an adult would give a 17.84 yard (16.31 m) pitch, still 10% longer than the model estimate, emphasising the influence of incorporating performance information in the scaling method. The performance data were based on a high standard of age group players thereby ensuring that the pitch length would still require bowlers to bowl well. The new length is close to the 16 yards estimated by an experienced ECB Level 4 coach (Chapter 3), but somewhat shorter than Cricket Australia's recent recommendation of 16 m (17.5 yards) for under-11s determined following a season of trials (Cricket Australia, 2017).

The temporal challenge for batters was estimated by simulating full toss (non-bouncing) deliveries and calculating the transit time from release to batter's crease. The 490 ms transit time estimated for adults is reasonable when compared with the 530 to 560 ms suggested for deliveries bouncing before reaching the batter by Justham et al. (2006) and Sarpeshkar et al. (2017). On a currently recommended pitch length of 20 yards under-11 batters have 30% to 50 % more time than adults in which to select and play their shot, even if the ball doesn't bounce. On the 14.83 m pitch calculated using the model the transit time was reduced to 566 ms for an average speed delivery, 16% longer than the adult figure, and 500 ms, still 2% longer than adults, for the fastest under-11 bowler's median speed. It is worth noting that even though the ball will arrive at the batter sooner (shorter target duration) on a shorter pitch, the bowlers are not bowling faster so that aspect of the task demand (target velocity) is unchanged, as therefore is the time during which the ball is in the striking zone.

Studies have shown that the improvement in coincidence timing accuracy improves mainly up to the age of 10 or 11 years (e.g. Benguigui and Ripoll, 1998; Kim, Nauhaus, Glazek, Young and Lin, 2013). This suggests that 11 year old batters should be capable of managing and may indeed benefit from the shorter time available in that it should help to redress the current situation where the temporal demand on junior batters is unlikely to encourage them to develop the anticipation skills characteristic of experts (Farrow and Reid, 2012; Müller and Abernethy, 2012; Weissensteiner et al., 2008). The reduced time available on a shorter pitch should lead by implicit learning to batters attending more to bowlers' movements and the associated outcomes of those movements, and to them exploring a more varied range of shots in response. Real-world reassurance that young batters can manage with a greater temporal demand is evident from Chapter 4 where it was found that on 16 yard (14.63 m) pitches, county under-10 and club under-11 batters played a wider variety of shots and ran more, and also from the fact that players frequently bat successfully in older age groups where the bowling is faster.

Timmerman et al. (2015) actually based their scaling ratio for tennis court dimensions and net height on the temporal demands of the game by using the racket to racket time between groundstrokes on a full sized court for boys (averaging 9.7 years of age) and elite adults. Their ratio was 0.76 compared with a ratio of 0.74 between the model generated pitch length for under-11s and adults on a full length pitch, although had their players been older (or ours younger) the difference between ratios would probably have been greater. Scaling the cricket pitch for under-11s on the basis of the transit time for a full toss on a full length cricket pitch (similar to the method of Timmerman et al.) results in a ratio of 0.60 if the average under-11 bowling speed is compared with an adult speed of 35 $m.s^{-1}$. This would mean a pitch length of 12.07 m, requiring a ball projection angle of -13.6° in order for the ball to bounce in the centre of the good length region; clearly a much steeper angle than typically found for stock deliveries by adults and therefore neither realistic nor desirable.

Dupuy, Motte and Ripoll (2000) illustrated that, in the absence of aerodynamic factors, projectile range sensitivity to speed and projection angle varied substantially depending upon the projection angle itself. The range-projection angle curve has a fairly broad, flat peak for projection angles in the 30 to 60° region typical of shot put, basketball free throws, kicking for distance and petanque for example (Dupuy et al., 2000; Hamilton and Reinschmidt, 1997; Linthorne, 2001; Linthorne and Patel, 2011). However for projection at or just below horizontal, as in cricket bowling and tennis serving, the curve is relatively steep, although it becomes flatter as the projection angle becomes more downward (Figure 6.3). The sensitivity of Flight Distance to projection angle variability is reduced by approximately a third between -0.7° (the average projection angle of for top under-11 bowlers on a 19 yard pitch) and -6.2° suggested here. What is more, a delivery bouncing in the good length region can be achieved with a 40% greater range of angles on the shorter pitch (a "projection angle window" of 2.8° compared with 2.0°). Therefore a shorter pitch means a larger margin of error in projection angle when attempting to hit the same pitch region, meaning that bowling outcomes are likely to be more consistent even if the individual bowler is just as variable in ball projection angle. This could also benefit batters as inconsistencies in release angle will result in smaller changes to where the ball bounces, so helping shot selection.

Release height and distance are related to stature and technique, but their influence on pitch length is small. So while the pitch length in this study was based on the average height of an 11 year old it would still be appropriate for taller and shorter players within or close to the age group. Furthermore even release speed has a limited influence on predicted pitch length at projection angles below horizontal, with the gradient of the Flight Distance-release speed curve being lower at ball projection angles further below horizontal (Figure 6.2).

Given the importance of the projection angle it seems sensible to limit the need for players to adjust it as they mature, that is to say, scale the pitch appropriately with projection angle as a determiner of the length. By incorporating realistic ball release parameters in the pitch scaling method, bowlers should be able to keep the fundamentals of their technique the same as they develop physically and focus more on subtler aspects of pace bowling such as generating swing and movement off the pitch.

Using release height and distance as a proportion of stature indicates but does not completely specify technique. Further research should address in more detail the influence of pitch length on bowling technique, both in comparison with recommended technique and with respect to the propensity for injury on pitches shorter than those recommended by Elliott et al. (2005).

The model calculation that a 14.83 m pitch would enable bowlers to bowl a good length ball when projecting the ball at -6.2° is slightly at odds with the finding reported in Chapter 4 that bowlers released the ball at -4.2° on a 16 yard (14.63 m) pitch. This might appear to suggest that the pitch should be shorter than 16 yards rather than slightly longer, however that is unlikely to be the case. In the bowling study the mean front foot position for the bowlers was 0.36 m behind the bowling crease, while the model assumes the rear of the front foot to be at the back edge of the crease, the limit of a legal delivery; on average the bowlers were effectively bowling on the equivalent of a 14.99 m pitch. Furthermore in the absence of a batter at the crease, bowlers tend to judge their length by trying to bowl such that the ball bounces close to the height of the stumps; the indoor surface used was designed for elite pace bowlers and as such had more bounce, meaning that a fuller ball (i.e. shallower projection) would still bounce quite high. Finally, the participants were limited by safety directives to bowling two overs on each of two pitch lengths (in addition to their practice deliveries), which may mean that they had not completely adapted their bowling to the pitch length. A study of ball release by bowlers on outdoor, turf pitches should be considered to clarify this, particularly with bowlers who have played on the pitch length for several weeks and with batters in position when collecting data.

Unlike some sports where there are constraints such as walls or fences, or where multiple line markings can cause confusion, in cricket adapting the pitch is straightforward, relying only on painting lines on the turf and positioning the stumps. The grass grows quickly and is mown frequently, removing the lines, allowing the same part of the ground to be re-marked at a different length and used for another age group. There is little reason therefore not to make the pitches fit the players better.

6.5 CONCLUSIONS

Scaling the pitch length using the method presented here enables bowlers to release the ball more like elite adult bowlers and if adopted throughout the junior age groups it will remove the need for bowlers to change their ball release point as they develop. Projecting the ball at a more downward angle also reduces the inaccuracy in length that variability in ball projection angle produces, leading to more success. For batters, the scaled pitch length should afford them the opportunity to learn and play a greater variety of shots, while the reduced time available to them will encourage greater attention to the bowlers and help them to develop the anticipation skills characteristic of skilled adult batters.

CHAPTER 7
SUMMARY AND CONCLUSIONS

The purpose of the research was to evaluate the effects on junior cricket of playing on a shorter pitch and ultimately to determine the optimal pitch length for the under-11 age group. This chapter summarises the four studies, addresses the questions posed in the Introduction, considers possible limitations and potential applications of the method, and suggests further research possibilities.

7.1 THESIS SUMMARY

7.1.1 THE EFFECTS ON MATCHES OF REDUCING THE PITCH LENGTH

This study evaluated the effect of reducing the pitch length on batting, bowling and fielding. County under-10 and club under-11 matches were analysed, ten played on pitch lengths currently recommended by the England and Wales Cricket Board (ECB), 19 yards (17.37 m) or 20 yards (18.28 m) respectively, and ten played on 16 yard (14.63 m) pitches. Differences between measures of batting, bowling and fielding were calculated to assess the effects of the shorter pitch length.

7.1.2 THE INFLUENCE OF PITCH LENGTH ON BALL RELEASE

A review of the literature revealed that standard deliveries by elite pace bowlers are typically projected at around 7° below horizontal. By contrast, young players currently appear to need to release the ball almost horizontally in an effort to get the ball to bounce close enough to the batter. It was anticipated that shortening the pitch could be a simple way to help young bowlers to release the ball at a better angle and with more consistency. Twenty county or best in club age group under-10 and under-11 right-arm seam bowlers were analysed bowling on two different pitch lengths (16 and 19 yards). An 18 camera Vicon Motion Analysis System operating at 300 Hz was used to track markers attached to the left heel, medial and lateral epicondyles of the right wrist and back of the right hand, as well as the ball. Ball speed, angle and position (with respect to the bowler's front heel) at release were calculated and compared between the two pitch lengths.

7.1.3 THE EFFECT OF PITCH LENGTH ON SHOT SELECTION

This study sought to determine whether playing on a shorter cricket pitch would lead batters to make more appropriate decisions about whether to play front foot or back foot shots. Based on a Probit analysis of the shots played by top order batters against seam bowling in county under-10 matches, an age-specific "good length" region was derived. This was where batters were uncertain whether to play on the front or back foot. It was then possible to define deliveries as "short" or "full" depending upon whether they bounced further from or nearer to the batter than the good length region. The proportion of back and front foot shots to balls of short and full length played in club and county matches on currently recommended and 16 yard pitches was calculated to compare the effect of the pitch length on the shot choices.

7.1.4 SCALING THE CRICKET PITCH TO FIT THE PLAYERS

A method of scaling the cricket pitch length was presented which is based on the age-specific ball release position and speed of the bowlers determined in Chapter 4, the good length distance determined in Chapter 5 and a release angle close to that of elite pace bowlers as reported in the literature. The release angle was corrected from -7° to -6.2° to allow for the extreme height of elite bowlers compared to average adults. The pitch length thus calculated would enable young bowlers to bowl good length deliveries while releasing the ball at an angle approaching that of elite adult pace bowlers. Furthermore releasing the ball at a steeper angle would result in less sensitivity of the flight distance to the inevitable variability in release speed and angle. This makes the bowlers' task somewhat simpler and may also help the batters' as small inconsistencies in release angle will cause smaller variations in delivery length. Nevertheless, the temporal demand will be greater for the batters on the shorter pitch, though against typical bowling speeds this still affords approximately 16% more time than an adult facing a typical elite pace bowler. The reduction in time available to batters should implicitly encourage the development of anticipation skills which characterize skilled batting.

7.2 RESEARCH QUESTIONS

How does playing on a shorter pitch affect objective measures of performance in junior cricket matches?

Compared with matches on the existing pitch length recommendations, in club and county matches on 16 yards, running between the wickets increased by 22% and 39% respectively, while boundary fours and sixes decreased by 54% and 68%. Deliveries played to the Mid-wicket area decreased by 44% in club and 33% in county matches, both accompanied by a more even distribution of fielding opportunities. Club matches saw a 15% increase in playable deliveries, largely due to fewer deliveries bouncing twice. Attempted shots, full toss No balls and Wide balls changed negligibly.

How do young bowlers bowl on the currently recommended pitch length?

On a 19 yard pitch the group mean of the individual median ball release speeds and angles of twenty county and top club under-10 and under-11 bowlers were found to be 21.1 $m.s^{-1}$ at an angle of -0.7°, with the median release angle for eight of the twenty bowlers being above horizontal. The mean ball release angle confirms the belief that even good bowlers tend to bowl quite flat in order to achieve the required distance.

How does bowling on a shorter pitch length change how young bowlers bowl?

The same bowlers were found to project the ball on average 3.4° further below horizontal on a 16 yard pitch compared with the 19 yard pitch, while ball speed and position at release changed negligibly. Pitch length did not affect the consistency of the release parameters. The shorter pitch led to a ball release angle closer to that of elite bowlers without changing release speed, and this should enable players to achieve greater success and develop more variety in their bowling.

What is a good length for junior seam bowlers to bowl?

Based on a Probit analysis of the shots played by top order batters against seam bowling in county under-10 matches, an age-specific “good length” region between 5.0 yards and 6.5 yards (4.57 to 5.94 m) from the batters stumps was derived. The reasonably even numbers of front and back foot shots to balls landing in this area demonstrates the decision required by batters and therefore the added difficulty of the task which bowlers can seek to exploit.

How does pitch length affect the batters’ shot selection?

Compared with matches on the currently recommended 20 or 19 yard pitches, club under-11 and county under-10 match data revealed that when playing on a 16 yard pitch batters played more back foot shots to short balls and county batters also played more front foot shots to full balls. For batters a shorter pitch should strengthen the coupling between perception of delivery length and appropriate shot selection, and the increased task demand should lead to improved anticipation, both key features of skilled batting.

What is the optimal pitch length for the age group?

A pitch length of 16.22 yards (14.83 m) was calculated, 19% shorter than previously recommended by the ECB for under-11s. This will enable a more functionally similar bowling action and also place more realistic demands on the batters.

7.3 LIMITATIONS AND FUTURE STUDIES

A number of limitations and suggestions for further work have been discussed in preceding chapters, however some general observations link to possible further research in the area of modified cricket for young players.

This research has focused on a particular age group, and while the findings could reasonably be extrapolated to other ages (see Appendix G for some further work in this area), the method used in each of the studies could be applied in detail to other ages. Furthermore, with the exception of a small number of girls playing in the matches analysed, the studies have used male participants. While boys and girls regularly play club cricket together, extending the work to look specifically at female cricketers is an obvious avenue which should be pursued.

If (as seems to be likely) shorter pitches are broadly recommended by the ECB, follow-up analysis of ball release angles in particular would reveal the extent to which the anticipated changes have taken place and whether bowlers do indeed maintain a similar release angle as they develop. From a participation perspective, it would be interesting to determine whether player retention improves in coming years in response to the improvements in involvement which the study reported in Chapter 3 found. Similarly, while there will always be a place for tall fast bowlers, introducing pitches which are better suited to the players could mean that more “less tall” players persist with seam bowling and possibly cricket in general.

The compromise between collecting data in the field and in more controlled conditions is especially pertinent with regard to junior cricket. It is common for junior club matches to be played on pitches which receive far less preparation than 1st XI pitches and they are rarely covered to keep them dry. As a consequence club (but not county) junior matches are usually played on slower, lower bouncing surfaces than the indoor facility used in the study reported in Chapter 4. Playing on a shorter pitch will enable a steeper ball release angle and so a higher rebound should be obtained, however the rebound characteristics of junior pitches compared with senior team pitches, and possibly artificial surfaces, could be investigated with a view to specifying a modified cricket ball which would more closely reproduce the bounce seen in adult cricket.

In addition to the rebound properties of the ball, its size and mass are worthy of attention. While cricket bats can be bought in a great range of sizes and masses, cricket balls for players up to and including the under-13 age group are specified to be 133 to 144 g in mass and 205 to 220 mm in circumference, compared with 156 to

162 g and 224 to 229 mm for the men's ball (MCC, 2017a). Thus on average the junior ball has 13% less mass and only a 6% or 4.4 mm smaller diameter. The ball for women's cricket falls between the two, but in diameter is allowed to be smaller than the upper limit of a junior ball or bigger than the lower limit for a men's ball.

Perhaps in part due to the difficulty of gripping a ball which is large relative to the players' hands, very few in the age group studied here have developed a recognizable and effective spin bowling technique. For this reason it was reasonable to focus on seam bowling when assessing the effect of changing the pitch length on ball release. Discussions with county coaches have suggested that a shorter pitch enables and encourages spin bowlers to spin the ball harder which is clearly a desirable outcome, but one which warrants corroboration. Some coaches have mentioned that the presence of a batter at the crease helps spin bowlers to adapt their length, so including a batter in any data collection should be considered.

As noted in Chapter 3, it was not possible to dictate the boundary sizes used in the matches analysed which therefore affected the run scoring. The size of the boundary has an effect on the scoring opportunities and shot choices available to batters but, given factors such as individual ground limitations, slopes and recent weather conditions, being narrowly prescriptive about boundary sizes is difficult. Nevertheless some guidelines could be developed based on factors such as the distance a typical age group batter can hit a six (using a variety of shots) or the distance players can throw the ball based on bat exit or throwing speeds. The boundary shape could also be manipulated, for example by shortening the boundary between Mid-on and Mid-off to reward shots into this area. Data on bat exit speeds by junior batters could also be used to inform studies of ball catching/avoidance similar to those conducted in baseball.

Away from cricket, tennis court and net height scaling has predominantly been based, at least loosely, on player stature (the work of Timmerman et al. (2015) being an exception). However, with the serve being such an important part of the game it might be revealing to attempt to scale the court, including service box, by attempting to achieve functional similarity between the serve of age group and adult players. It may be that net height should be scaled according to relative stature before modelling the serve to enable age group players to project the ball at an angle close to that typical of adult servers, in a similar way to the pitch scaling in this study.

7.4 CONCLUSIONS

This research adds to the growing body of work supporting the benefits of scaling the playing environment in junior and youth sports and has emphasized the incorporation of the physical abilities of the players rather than simply their size when making adaptations. Match play on shorter pitches had benefits for bowlers, batters and fielders, resulting in matches that were more engaging, which should encourage player retention. Scaling the pitch length using the method presented here enables bowlers to release the ball more like elite adult bowlers and if implemented throughout the junior age groups it would remove the need for bowlers to change their ball release point as they develop. For batters, the scaled pitch length should afford them the opportunity to learn and play a greater variety of shots, while the reduced time available to them will encourage greater attention to the bowlers and help them to develop the anticipation skills characteristic of skilled adult batters. A cricket pitch is probably the simplest of all sports playing environments to modify so coaches and governing bodies should consider implementing shorter pitches as a means to enhance all aspects junior cricket.

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APPENDIX A
PARTICIPANT INFORMATION AND INFORMED CONSENT

APPENDIX A.1 PILOT STUDY

Participant Information Sheet

Main investigator: Dr Mike Harwood, M.J.Harwood@lboro.ac.uk
Supervisor: Dr Mark King, M.A.King@lboro.ac.uk

Purpose of the study
This research is being conducted by Loughborough University and the England & Wales Cricket Board to investigate the effects of changing the playing environment on the outcomes and enjoyment of youth cricket matches.

Procedures
Video of the matches will be recorded and statistically analysed to assess the effects of changes to the playing environment. Individual performances are not being assessed. Player height may be recorded at one of the sessions.

Activities
Indoor cricket matches organized and run by Derbyshire Cricket Board coaches will take place at Chellaston Academy, Derby.

Questions
The investigator will be pleased to answer any questions you may have either at the sessions or by phone (07870 xxxxxx) or email M.J.Harwood@lboro.ac.uk

Withdrawal
You are free to withdraw at any time and do not need to give your reasons for doing so.

Confidentiality
Beyond the usual information required to score the games, data collected will not identify individuals. All information will be kept securely and remain confidential.
It is possible that video clips may be used in presentations to coaches and other researchers but all subjects will remain anonymous.

If you are unhappy with how the research was conducted, please contact Ms Jackie Green, the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Ms J Green, Research Office, Hazlerigg Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: J.A.Green@lboro.ac.uk

The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at
http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm.

APPENDIX A.2 MATCH DATA COLLECTION

Introductory letter- County matches

Dear players and parents,

As part of an ECB/Loughborough University research project looking at the youth cricket playing environment, I am visiting a number of county age group matches this season. I will be video recording the game from a fixed position beside the pitch, focusing on the wicket from stumps to stumps, to count various game measures, and completing a score sheet in the usual way. I might also measure height and take date of birth information at some matches, but this would be anonymous data.

Individual player performances are not being assessed and ultimately all data from each match will be combined with that from other matches, further ensuring player anonymity.

Please take a moment to read the Participant Information and do get in touch with me in advance or on the day if you have any questions or concerns.

There is an Informed Consent sheet at the foot of this document. If you are happy for your child to be included I would be grateful if you would print a copy of that page, complete it with your young cricketer and return it to me on the day or via your team manager.

Many thanks for taking time to read this and thanks in anticipation for agreeing to let your child be part of what we hope will lead to positive developments within the youth game.

Best regards,

Mike Harwood

Mike Harwood PhD
Sports Biomechanics
School of Sport, Exercise and Health Sciences
Loughborough University, Loughborough, LE11 3TU
Tel. 07870 xxxxxx
Email M.J.Harwood@lboro.ac.uk

Introductory letter- Club matches

Dear players and parents,

As part of an ECB/Loughborough University research project looking at the youth cricket playing environment, I am visiting a number of U11 hardball matches this season. I will be video recording the game from a fixed position beside the pitch, focusing on the wicket from stumps to stumps, to count various game measures, and completing a scoresheet in the usual way. I might also measure height and take date of birth information at some matches, but this would be anonymous data.

Individual player performances are not being assessed and ultimately all data from each match will be combined with that from other matches, further ensuring player anonymity.

Please take a moment to read the Participant Information and do get in touch with me if you have any concerns.

On the day of the match there will be a consent sheet for each team which I would be grateful if you and your young cricketer would sign. If you are not at the match, another adult (e.g. the team manager) can sign on your behalf, but I would appreciate it if you would email me to confirm your consent if this happens.

Many thanks for taking time to read this and thanks in anticipation for agreeing to let your child be part of what we hope will lead to positive developments within the youth game.

Best regards,

Mike Harwood

Mike Harwood PhD
Sports Biomechanics
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Participant Information Sheet

Main investigator: Dr Mike Harwood, M.J.Harwood@lboro.ac.uk
Supervisor: Dr Mark King, M.A.King@lboro.ac.uk

Purpose of the study
This research is being conducted by Loughborough University and the England & Wales Cricket Board to investigate the effect of pitch lengths on the outcomes and enjoyment of youth cricket. It is hoped that the findings will result in recommendations which will improve player skill development, involvement and enjoyment of the game.

Procedures
Video recordings of cricket matches will be made to enable data regarding the characteristics of the game and player involvement to be gathered. Individually identifiable performances are not being assessed. Limited player details, for example height and age, will be recorded at some of the sessions.

Activities
Players will be participating in their normally scheduled cricket matches. In most cases they will be minimally aware of the study being conducted.

Questions
The investigator will be pleased to answer any questions you may have in person or by phone (07870 xxxxxx) or email M.J.Harwood@lboro.ac.uk

Withdrawal
After you have read this information and asked any questions you may have, you will be asked to complete an Informed Consent Form, however you are free to withdraw from the study at any time and do not need to give your reasons for doing so.

Confidentiality
Data collected will not identify individuals and will remain confidential. All information will be kept securely and retained for a maximum of ten years. It is possible that video clips or still images may be used in presentations to coaches and other researchers but all subjects will remain anonymous.

If you are unhappy with how the research was conducted, please contact Ms Jackie Green, the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Ms J Green, Research Office, Hazlerigg Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: J.A.Green@lboro.ac.uk

The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm.

APPENDIX A.3 BOWLING DATA COLLECTION

Participant Information Sheet

Main investigator: Dr Mike Harwood, M.J.Harwood@lboro.ac.uk Tel. 07870 xxxxxx

Supervisor: Dr Mark King, M.A.King@lboro.ac.uk Tel. 01509 xxxxxx

What is the purpose of the study?

This study involves a biomechanical analysis of bowling actions on different length wickets. Data on ball speeds and trajectories, body positions and motion will be collected from young bowlers and used in a mathematical model to calculate the optimal length of the pitch.

Who is doing this research and why?

This study is part of research being carried out by Dr Mike Harwood, under the supervision of Dr Mark King, supported by Loughborough University and the England & Wales Cricket Board investigating the effects of changing the pitch length on the outcomes and enjoyment of youth cricket matches.

Are there any exclusion criteria?

There is a short medical questionnaire below which must be completed prior to the study.
The testing protocol requires the attachment of reflective markers to the skin of the arms, legs and upper body so subjects must be prepared to bowl wearing just shorts, low socks and training shoes, and should not be allergic to medical adhesive tape.

What will I/my child be asked to do?

You will be asked to attend the ECB National Cricket Performance Centre at Loughborough University at a specific time.
During your session, your child will have reflective markers positioned on his/her body prior to completing a short warm-up. The main data collection will involve bowling four overs on two or three different pitch lengths, with suitable rest between deliveries and overs. The deliveries will be recorded using a three-dimensional high speed motion analysis system and ordinary high speed cameras. Following the bowling, body measurements (lengths, widths and perimeters of the arms, legs, trunk and head, plus body mass) will be recorded so that the body can be accurately modelled.

Once I take part, can I change my mind?

Yes! You are free to withdraw at any time, before, during or after the session, for any reason and you will not be asked to explain your reasons for doing so.

How long will it take?

From arrival at the centre to departure will take in the region of 60 to 75 minutes.

What personal information will be required?

The medical questionnaire below and the data collected at the session, as outlined above.

Are there any risks in participating?

You/your child will be bowling indoors, therefore it is considered that the risks associated with the data collection will be no greater than those normally associated with indoor bowling.
There is an extremely slight risk of an allergic reaction to the adhesive tape used to attach the reflective markers.

Will my taking part in this study be kept confidential?

All information collected during this biomechanical assessment will be stored securely in accordance with the Data Protection Act. Your (child's) identity will remain confidential in any material resulting from this work.
It is possible that video clips may be used in presentations to coaches and other researchers, but all subjects will remain anonymous. No clips or stills will be used on 'social media' or websites.

I have some more questions; who should I contact?

Please don't hesitate to contact Dr Mike Harwood or Dr Mark King (details above) before, during or after the study.

What will happen to the results of the study?

The outcomes of this study will be presented to the ECB, at academic conferences and in academic journals. It is possible that there will be press releases related to the study. No individual subjects will be identified. The results will inform possible future changes to pitch length recommendations for youth cricket.

Is there anything I need to do before the sessions?

Contact Mike Harwood if you have any questions. Once you are entirely happy with the information contained here, please print and complete the Medical Questionnaire and Informed Consent form below, and bring it with you to the data collection.
Please inform Mike Harwood if you will be unable to attend at the agreed time.

What type of clothing should I wear?

Bowlers should come in sports clothing (tracksuit, joggers and hoody, etc.) with shorts underneath and low socks. Please wear indoor training shoes.
To help with the adhesion of the markers, please avoid excessive use of moisturizers on the skin that day.

What if I am not happy with how the research was conducted?

If you are unhappy with how the research was conducted, please contact Ms Jackie Green, the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Ms J Green, Research Office, Hazlerigg Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: J.A.Green@lboro.ac.uk
The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm

PARENTAL PRE-SELECTION MEDICAL QUESTIONNAIRE

Please read through this questionnaire, **BUT DO NOT ANSWER ANY OF THE QUESTIONS YET**.

Once you have read the questionnaire, if you are happy to complete it please do so. If there are questions you would prefer not to answer, or would like assistance to discuss any of the questions, please inform us.

If you would like to withdraw your child from the study, please tick the box labelled "I wish to withdraw" immediately below. You should also tick the box labelled "I wish to withdraw" if there is any other reason for you not to take part.

	tick appropriate box
I wish to withdraw	☐
I am happy to answer the questionnaire	☐

If you are happy to answer the questions posed below, please proceed. Your answers will be treated in the strictest confidence.

---

* Delete as appropriate

1. Is your child at present recovering from any illness or operation?

   YES/NO*

2. Is your child suffering from or has s/he suffered from or received medical treatment for any of the following conditions?

   a. Heart or circulation condition

      YES/NO*

   b. High blood pressure

      YES/NO*

c. Any orthopaedic problems

YES/NO*

d. Any muscular problems

YES/NO*

e. Asthma or bronchial complaints

YES/NO*

3. Is your child currently taking any medication that may affect his/her YES/NO* participation in the study?

4. Is your child recovering from any injury?

YES/NO*

5. Is your child epileptic?

YES/NO*

6. Is your child diabetic?

YES/NO*

7. Is your child allergic to sticking plasters?

YES/NO*

8. Does your child have any other allergies? If yes, please give details below.

YES/NO*

____

____

____

____

9. Are you aware of any other condition or complaint that may be affected by participation in this study? If so, please state below.

____

____

____

____

APPENDIX A.4 INFORMED CONSENT FORM

(To be completed after Participant Information Sheet has been read)

The purpose of this study has been explained to me.

I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Approvals (Human Participants) Sub-Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my/my child's participation.

I understand that I am/s/he is under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information provided will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Player's name ____

Player's signature ____

Player's Date of Birth ____

I agree to my child's participation in this study.

Parent's name ____

Parent's signature ____

Investigator's signature ____

Date ____

APPENDIX B
PILOT STUDY

INTRODUCTION

Three games were played in a pairs format by county under-10 squad players over a period of two months. Three pitch lengths were trialled after discussion with two senior county coaches who ran the sessions. The first game was played over 19 yards (the under-10 pitch length recommendation), the second over 16½ yards and the third over 14 yards. The players were given no information about the changes to the pitch length nor instructions about how they should adapt.

All games were played in a sports hall on a roll-out mat using Dukes indoor balls. The players batted in pairs for four overs. Four pairs played in the first two games (16 overs in total) but only three pairs were available for the final game (12 overs). None of the bowlers were spinners. A scoresheet was completed during the games and video recorded from a gallery position affording an overview of the pitch.

The scoresheet and video were analysed to quantify the batting and bowling performances on the three pitch lengths. Each delivery was classified as short, good length or overpitched (aided by the sports hall floor markings), and a record of how the ball was played (front or back foot, scoring, left or played and missed) was made. Wide balls and high No balls (‘beamers’) were also counted.

RESULTS

19 yard game

- 40% of deliveries were short-pitched, but only 5% of shots were played off the back foot.
- Some short balls had descended to a height to drive off the front foot when they reached the batter (and three were double bouncers).
- 16 out of 96 deliveries were Wides (17%).

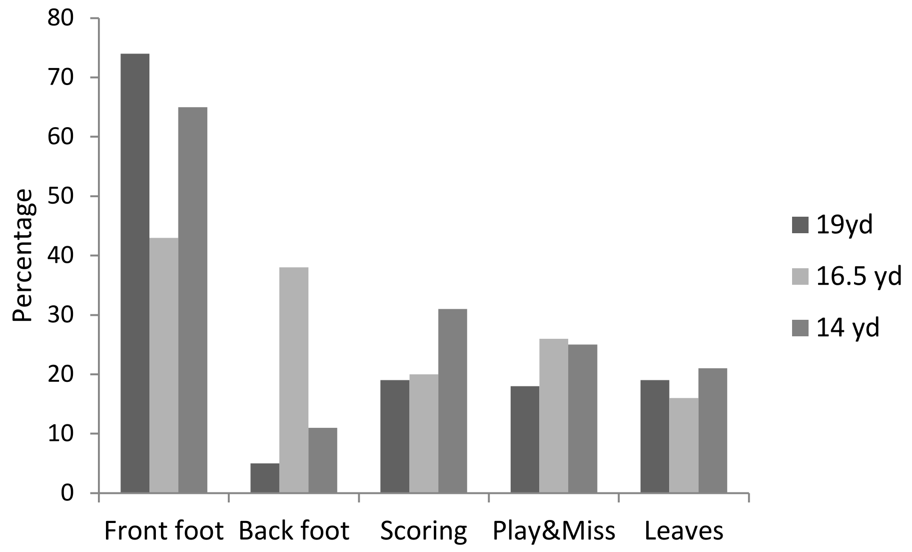


Figure B.1 Batting summary.

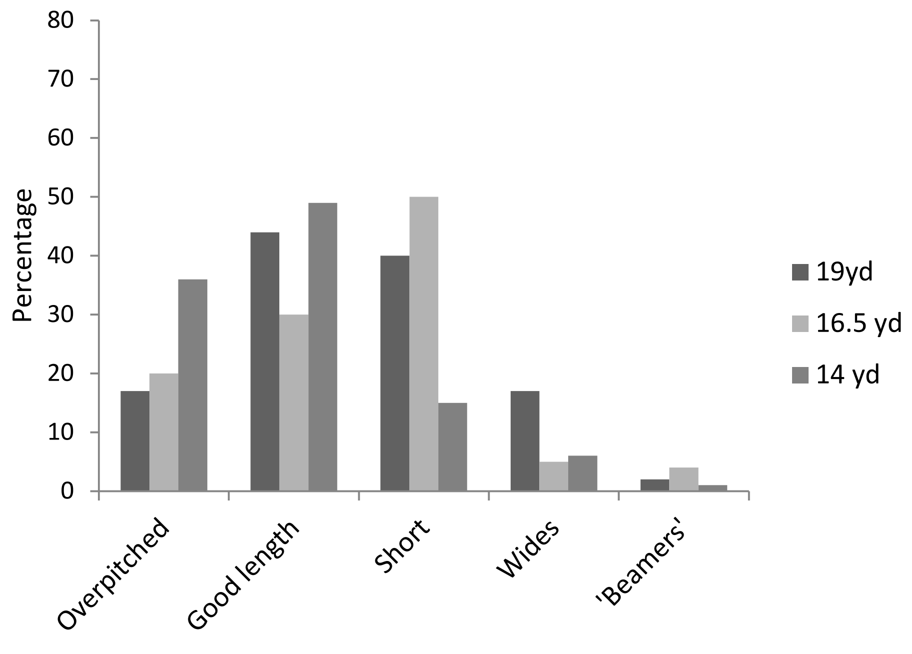


Figure B.2 Bowling summary.

- Play and misses, ‘leaves’ and scoring shots were each 18-19% of the deliveries faced.
- Two balls were beamers.

16½ yard game compared with 19 yard

- 50% of deliveries were short, but the proportion of back foot shots increased to 38% (from 5%).
- Some short balls were still driveable off the front foot, but none were double bouncers.
- Only five balls were Wide and four were beamers.
- Scoring shots and leaves were similar in proportion to before (20% and 16% respectively)
- Play and miss percentage increased to 26% (from 18%).
- 49 runs off the bat compared with 40 in the previous game.

14 yard game compared with other two

- Short balls dropped to 15% and back foot shots dropped to 11%.
- Wides and beamers still low (4 and 1 respectively).
- Scoring shots increased to 31%, though some were “edges”.
- 63 runs from the bat despite only three pairs (so ¾ of the overs).
- Play and miss percentage similar to 16½ yard game (25%); leaves were not substantially higher than on other pitch lengths (at 21%).

SUMMARY

The 16½ yard pitch encouraged back foot shots and hurried the batters slightly, as evidenced by the higher play and miss percentages. The proportion of front and back foot shots was also more even. Wide deliveries however were reduced and there was little change in the number of high full tosses.

The 14 yard pitch may be too short for the bowlers (judging by the reduction in short balls and increase in overpitched balls). Shortening the pitch too much is likely to disadvantage the bowlers by making it difficult to bowl a good length with a natural action.

The county coaches involved in the trial (and who had been running more games on the same pitch lengths with the other half of the squad) were encouraged by the changes the shorter pitches brought and the general feeling that the games had more "pace" and involvement. They concluded that 14 yards was probably too short but that on grass 16½ yards might possibly be a little long. Their recommendation was to trial 16 yards for under-10 and under-11 outdoor matches.

APPENDIX C
SHOT DISTRIBUTION RECORDING

The shot distribution during one innings of 16 overs was recorded by two independent observers with the following results:

Field area	Shot count		Difference
	Investigator A	Investigator B	
Bowler/Wicket-keeper	36	36	0
Long leg	12	13	-1
Mid-wicket	14	15	-1
Mid-on	3	3	0
Mid-off	2	3	-1
Cover	16	15	+1
Third man	14	13	+1
Total	97	98	-1

Two shots which were fielded close to the border of adjacent field areas appear to have been recorded differently by the investigators. One passing behind the wicket-keeper was recorded as being fielded at Third man by Investigator A but at Long leg by Investigator B; another hit on the off-side was recorded as being fielded at Cover by Investigator A and at Mid-off by Investigator B. There was also a one shot discrepancy between investigators at Mid-wicket.

APPENDIX D
COUNTY UNDER-10 AND CLUB UNDER-11 BOWLER DATA

Successful bowlers tend to be tall, perhaps because they must cope with bowling on a relatively long pitch when young. Here, even those few who are below average stature for their age on the date of bowling (i.e. bowlers 1, 2, 10 and 19) are likely to be of at least average height for their *age group* at the beginning of the cricket season (data collected at the end of September; season commences in April/May).

	Age	Mass	Stature	
	years	kg	m	centile for age
1	11.9	32.2	1.43	24
2	11.8	32.9	1.43	26
3	11.6	47.0	1.52	78
4	11.5	41.3	1.47	56
5	11.0	57.9	1.58	98
6	11.0	33.0	1.47	70
7	11.0	32.7	1.46	65
8	11.0	39.8	1.44	54
9	10.9	38.1	1.43	51
10	10.9	37.1	1.42	45
11	10.8	36.2	1.44	59
12	10.7	34.4	1.42	52
13	10.7	42.7	1.54	96
14	10.6	35.2	1.51	92
15	10.5	30.2	1.42	57
16	10.5	40.6	1.44	68
17	10.5	40.2	1.42	57
18	10.1	54.9	1.59	100
19	9.9	30.4	1.36	38
20	9.2	39.8	1.40	82
			median	58

APPENDIX E
SPSS PROBIT ANALYSIS OUTPUT

APPENDIX E.1 16 YARD DATA

Data Information

		N of Cases
Valid		13
Rejected	Missing	0
	LOG Transform Cannot be Done	0
	Number of Responses > Number of Subjects	0
Control Group		0

Convergence Information

	Number of Iterations	Optimal Solution Found
PROBIT	14	Yes

Parameter Estimates

	Parameter	Estimate	Std. Error	Z	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
PROBIT[a]	length	9.816	1.085	9.045	.000	7.689	11.943
	Intercept	-7.573	.839	-9.023	.000	-8.413	-6.734

a. PROBIT model: PROBIT(p) = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm.)

Chi-Square Tests

		Chi-Square	df[b]	Sig.
PROBIT	Pearson Goodness-of-Fit Test	14.637	11	.200[a]

a. Since the significance level is greater than .150, no heterogeneity factor is used in the calculation of confidence limits.

b. Statistics based on individual cases differ from statistics based on aggregated cases.

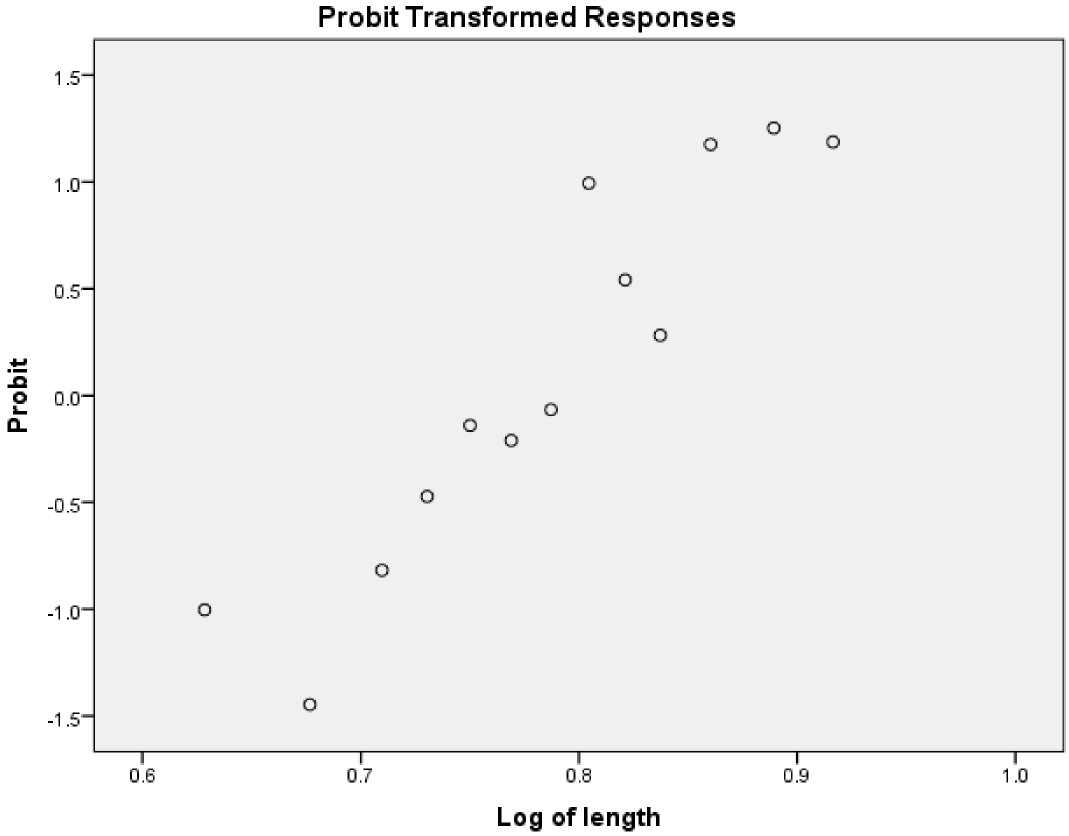
Cell Counts and Residuals

	Number	length	Number of Subjects	Observed Responses	Expected Responses	Residual	Probability
PROBIT	1	.628	38	6	3.040	2.960	.080
	2	.677	27	2	4.751	-2.751	.176
	3	.710	29	6	7.887	-1.887	.272
	4	.730	22	7	7.549	-.549	.343
	5	.750	18	8	7.502	.498	.417
	6	.769	24	10	11.764	-1.764	.490
	7	.787	19	9	10.655	-1.655	.561
	8	.804	25	21	15.671	5.329	.627
	9	.821	17	12	11.680	.320	.687
	10	.837	18	11	13.332	-2.332	.741
	11	.860	25	22	20.208	1.792	.808
	12	.889	19	17	16.647	.353	.876
	13	.916	17	15	15.684	-.684	.923

Confidence Limits

	Probability	95% Confidence Limits for length			95% Confidence Limits for log(length)[a]		
		Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
PROBIT	.010	3.424	2.930	3.793	.535	.467	.579
	.020	3.650	3.177	4.000	.562	.502	.602
	.030	3.801	3.344	4.138	.580	.524	.617
	.040	3.919	3.475	4.246	.593	.541	.628
	.050	4.017	3.586	4.335	.604	.555	.637
	.060	4.103	3.682	4.413	.613	.566	.645
	.070	4.180	3.769	4.483	.621	.576	.652
	.080	4.250	3.848	4.546	.628	.585	.658
	.090	4.315	3.921	4.605	.635	.593	.663
	.100	4.375	3.990	4.659	.641	.601	.668
	.150	4.634	4.285	4.895	.666	.632	.690
	.200	4.850	4.532	5.093	.686	.656	.707
	.250	5.044	4.753	5.273	.703	.677	.722
	.300	5.225	4.956	5.444	.718	.695	.736
	.350	5.398	5.149	5.612	.732	.712	.749
	.400	5.568	5.333	5.782	.746	.727	.762
	.450	5.737	5.512	5.957	.759	.741	.775
	.500	5.909	5.688	6.142	.772	.755	.788
	.550	6.086	5.862	6.339	.784	.768	.802
	.600	6.271	6.038	6.554	.797	.781	.816
	.650	6.468	6.219	6.790	.811	.794	.832
	.700	6.683	6.409	7.055	.825	.807	.849
	.750	6.922	6.616	7.359	.840	.821	.867
	.800	7.199	6.849	7.718	.857	.836	.888
	.850	7.535	7.126	8.165	.877	.853	.912
	.900	7.981	7.485	8.770	.902	.874	.943
	.910	8.093	7.574	8.923	.908	.879	.951
	.920	8.216	7.672	9.093	.915	.885	.959
	.930	8.354	7.780	9.284	.922	.891	.968
	.940	8.510	7.902	9.503	.930	.898	.978
	.950	8.692	8.044	9.759	.939	.905	.989
	.960	8.910	8.214	10.068	.950	.915	1.003
	.970	9.186	8.426	10.463	.963	.926	1.020
	.980	9.566	8.717	11.014	.981	.940	1.042
	.990	10.198	9.194	11.942	1.009	.964	1.077

a. Logarithm base = 10.


Probit Transformed Responses
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1.0
0.5
0.0
-0.5
-1.0
-1.5
Probit
0.6
0.7
0.8
0.9
1.0
Log of length

APPENDIX E.2 19 YARD DATA

Data Information

		N of Cases
Valid		13
Rejected	Missing	0
	LOG Transform Cannot be Done	0
	Number of Responses > Number of Subjects	0
Control Group		0

Convergence Information

	Number of Iterations	Optimal Solution Found
PROBIT	6	Yes

Parameter Estimates

			Std.			95% Confidence Interval	
	Parameter	Estimate	Error	Z	Sig.	Lower Bound	Upper Bound
PROBIT[a]	length	9.896	.988	10.012	.000	7.958	11.833
	Intercept	-7.432	.754	-9.854	.000	-8.186	-6.678

a. PROBIT model: PROBIT(p) = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm.)

Chi-Square Tests

		Chi-Square	df[b]	Sig.
PROBIT	Pearson Goodness-of-Fit Test	8.356	11	.681[a]

a. Since the significance level is greater than .150, no heterogeneity factor is used in the calculation of confidence limits.

b. Statistics based on individual cases differ from statistics based on aggregated cases.

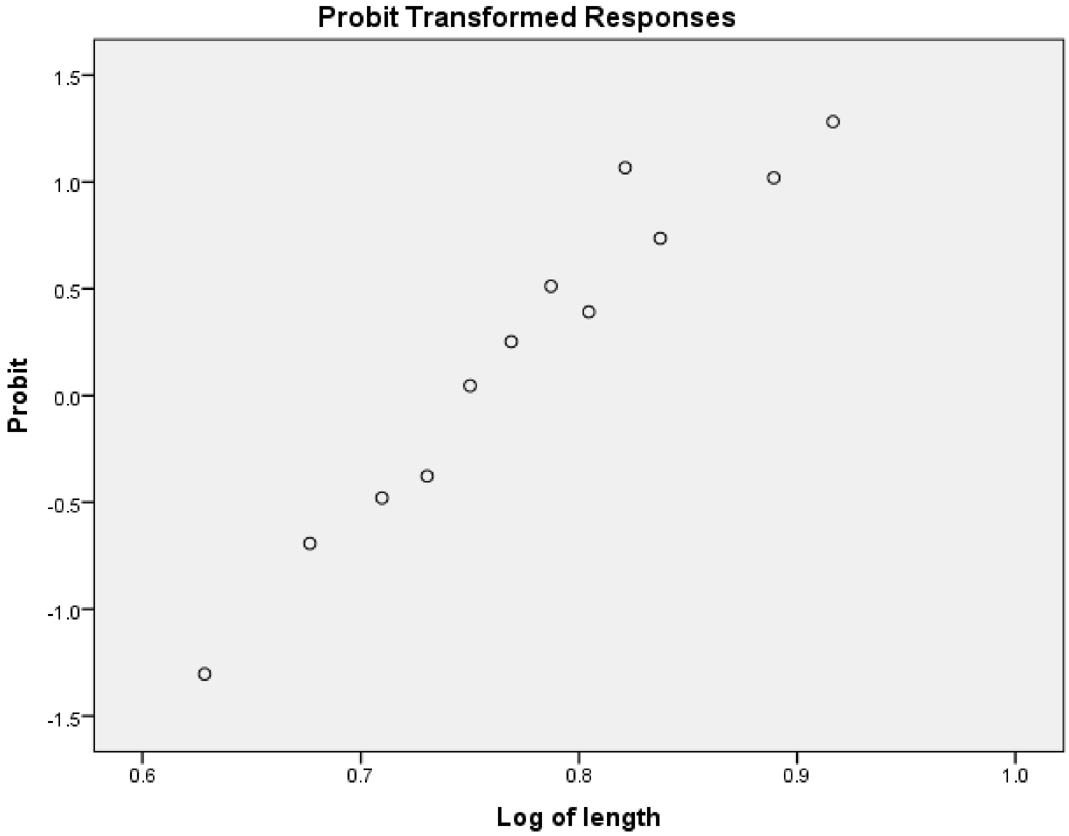
Cell Counts and Residuals

	Number	length	Number of Subjects	Observed Responses	Expected Responses	Residual	Probability
PROBIT	1	.628	52	5	5.849	-.849	.112
	2	.677	45	11	10.397	.603	.231
	3	.710	19	6	6.485	-.485	.341
	4	.730	17	6	7.125	-1.125	.419
	5	.750	27	14	13.405	.595	.496
	6	.769	25	15	14.267	.733	.571
	7	.787	23	16	14.709	1.291	.640
	8	.804	23	15	16.137	-1.137	.702
	9	.821	14	12	10.588	1.412	.756
	10	.837	26	20	20.887	-.887	.803
	11	.860	22	22	18.927	3.073	.860
	12	.889	26	22	23.775	-1.775	.914
	13	.916	20	18	18.984	-.984	.949

Confidence Limits

		95% Confidence Limits for length			95% Confidence Limits for log(length)[a]		
	Probability	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
PROBIT	.010	3.280	2.847	3.615	.516	.454	.558
	.020	3.495	3.078	3.815	.543	.488	.581
	.030	3.639	3.234	3.947	.561	.510	.596
	.040	3.751	3.357	4.050	.574	.526	.608
	.050	3.844	3.460	4.136	.585	.539	.617
	.060	3.926	3.550	4.211	.594	.550	.624
	.070	3.998	3.631	4.278	.602	.560	.631
	.080	4.065	3.704	4.339	.609	.569	.637
	.090	4.126	3.773	4.395	.616	.577	.643
	.100	4.183	3.837	4.447	.622	.584	.648
	.150	4.429	4.111	4.673	.646	.614	.670
	.200	4.634	4.342	4.862	.666	.638	.687
	.250	4.818	4.548	5.033	.683	.658	.702
	.300	4.989	4.738	5.195	.698	.676	.716
	.350	5.153	4.919	5.353	.712	.692	.729
	.400	5.314	5.093	5.510	.725	.707	.741
	.450	5.474	5.263	5.672	.738	.721	.754
	.500	5.637	5.432	5.840	.751	.735	.766
	.550	5.804	5.600	6.020	.764	.748	.780
	.600	5.979	5.771	6.214	.777	.761	.793
	.650	6.165	5.947	6.428	.790	.774	.808
	.700	6.368	6.133	6.667	.804	.788	.824
	.750	6.594	6.334	6.942	.819	.802	.841
	.800	6.856	6.561	7.266	.836	.817	.861
	.850	7.174	6.830	7.670	.856	.834	.885
	.900	7.595	7.179	8.216	.881	.856	.915
	.910	7.700	7.266	8.354	.887	.861	.922
	.920	7.816	7.360	8.507	.893	.867	.930
	.930	7.946	7.465	8.680	.900	.873	.938
	.940	8.093	7.584	8.876	.908	.880	.948
	.950	8.265	7.722	9.107	.917	.888	.959
	.960	8.471	7.886	9.385	.928	.897	.972
	.970	8.731	8.093	9.740	.941	.908	.989
	.980	9.090	8.375	10.234	.959	.923	1.010
	.990	9.685	8.838	11.065	.986	.946	1.044

a. Logarithm base = 10.


Probit Transformed Responses
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-1.5
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0.9
1.0
Log of length

APPENDIX E.3 COMBINED DATA

Data Information

		N of Cases
Valid		13
Rejected	Missing	0
	LOG Transform Cannot be Done	0
	Number of Responses > Number of Subjects	0
Control Group		0

Convergence Information

	Number of Iterations	Optimal Solution Found
PROBIT	6	Yes

Parameter Estimates

	Parameter	Estimate	Std. Error	Z	Sig.	95% Confidence Interval Lower Bound	Upper Bound
PROBIT[a]	length	9.795	.728	13.455	.000	8.368	11.222
	Intercept	-7.451	.559	-13.324	.000	-8.010	-6.892

a. PROBIT model: PROBIT(p) = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm.)

Chi-Square Tests

		Chi-Square	df[b]	Sig.
PROBIT	Pearson Goodness-of-Fit Test	10.587	11	.479[a]

a. Since the significance level is greater than .150, no heterogeneity factor is used in the calculation of confidence limits.
b. Statistics based on individual cases differ from statistics based on aggregated cases.

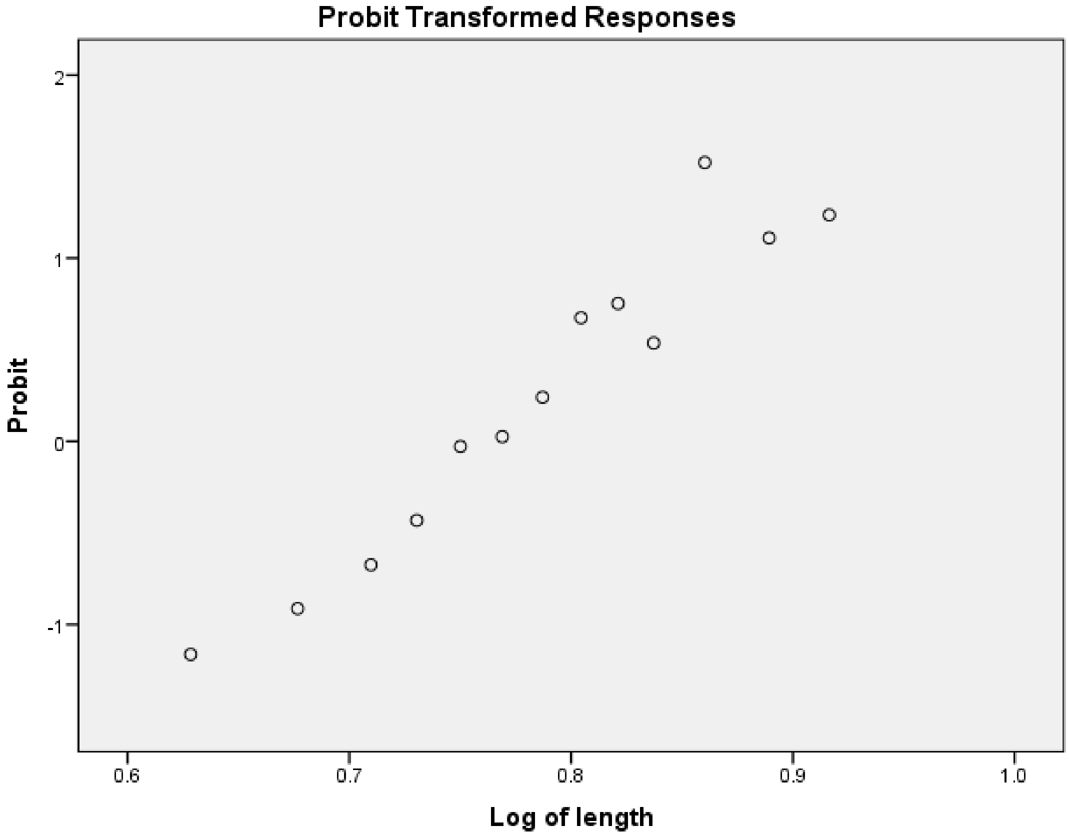
Cell Counts and Residuals

	Number	length	Number of Subjects	Observed Responses	Expected Responses	Residual	Probability
PROBIT	1	.628	90	11	8.773	2.227	.097
	2	.677	72	13	14.780	-1.780	.205
	3	.710	48	12	14.816	-2.816	.309
	4	.730	39	13	14.945	-1.945	.383
	5	.750	45	22	20.642	1.358	.459
	6	.769	49	25	26.088	-1.088	.532
	7	.787	42	25	25.285	-.285	.602
	8	.804	48	36	31.966	4.034	.666
	9	.821	31	24	22.419	1.581	.723
	10	.837	44	31	34.028	-3.028	.773
	11	.860	47	44	39.266	4.734	.835
	12	.889	45	39	40.324	-1.324	.896
	13	.916	37	33	34.648	-1.648	.936

Confidence Limits

	Probability	95% Confidence Limits for length			95% Confidence Limits for log(length)[a]		
		Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
PROBIT	.010	3.336	3.022	3.594	.523	.480	.556
	.020	3.557	3.256	3.803	.551	.513	.580
	.030	3.704	3.414	3.942	.569	.533	.596
	.040	3.819	3.537	4.050	.582	.549	.607
	.050	3.915	3.640	4.140	.593	.561	.617
	.060	3.999	3.730	4.218	.602	.572	.625
	.070	4.074	3.811	4.288	.610	.581	.632
	.080	4.142	3.885	4.352	.617	.589	.639
	.090	4.206	3.954	4.411	.624	.597	.645
	.100	4.264	4.017	4.466	.630	.604	.650
	.150	4.517	4.292	4.703	.655	.633	.672
	.200	4.729	4.522	4.902	.675	.655	.690
	.250	4.919	4.727	5.081	.692	.675	.706
	.300	5.095	4.918	5.249	.707	.692	.720
	.350	5.265	5.098	5.413	.721	.707	.733
	.400	5.431	5.273	5.576	.735	.722	.746
	.450	5.596	5.444	5.743	.748	.736	.759
	.500	5.764	5.614	5.915	.761	.749	.772
	.550	5.937	5.785	6.098	.774	.762	.785
	.600	6.117	5.960	6.293	.787	.775	.799
	.650	6.310	6.142	6.506	.800	.788	.813
	.700	6.520	6.335	6.743	.814	.802	.829
	.750	6.754	6.547	7.013	.830	.816	.846
	.800	7.025	6.788	7.330	.847	.832	.865
	.850	7.354	7.076	7.722	.867	.850	.888
	.900	7.790	7.451	8.249	.892	.872	.916
	.910	7.899	7.545	8.382	.898	.878	.923
	.920	8.020	7.647	8.529	.904	.883	.931
	.930	8.154	7.761	8.694	.911	.890	.939
	.940	8.307	7.890	8.882	.919	.897	.949
	.950	8.485	8.040	9.102	.929	.905	.959
	.960	8.698	8.219	9.368	.939	.915	.972
	.970	8.969	8.444	9.706	.953	.927	.987
	.980	9.341	8.753	10.175	.970	.942	1.008
	.990	9.959	9.261	10.962	.998	.967	1.040

a. Logarithm base = 10.


Probit Transformed Responses
Probit
2
1
0
-1
0.6
0.7
0.8
0.9
1.0
Log of length

APPENDIX F
RECORDED AND PREDICTED BALL BOUNCE LOCATION

Ball bounce locations for sixty deliveries by four bowlers were recorded at 200 Hz using a Panasonic DMC-FZ200 camera positioned perpendicular to the plane of the ball flight. Calibration lines marked on the floor along a region 4 m long and 1.5 m wide enabled ball bounce positions to be determined with respect to the bowler's end stumps. These bounce locations were compared with those determined by modelling ball flight as a projectile (neglecting air resistance) using the actual ball release position, speed and angle obtained from the Vicon analysis of these deliveries.

Video (m)	Model (m)	Difference (m)	Video (m)	Model (m)	Difference (m)
13.77	13.88	-0.11	13.07	13.20	-0.13
12.02	11.98	0.04	10.92	11.15	-0.23
10.42	10.45	-0.03	11.02	11.19	-0.17
12.62	12.68	-0.06	13.37	13.75	-0.38
13.97	13.96	0.01	11.37	11.41	-0.04
10.92	10.98	-0.06	13.12	13.44	-0.32
11.72	11.73	-0.01	11.57	11.84	-0.27
11.92	11.77	0.15	11.47	11.56	-0.09
13.07	13.08	-0.01	12.52	12.77	-0.25
10.62	10.55	0.07	12.02	12.33	-0.31
12.87	12.68	0.19	13.02	13.16	-0.14
14.22	14.27	-0.05	12.27	12.52	-0.25
11.17	10.91	0.26	12.07	12.38	-0.31
11.17	10.91	0.26	12.22	12.32	-0.10
11.57	11.22	0.35	10.92	11.10	-0.18
11.72	11.49	0.23	13.47	13.97	-0.50
11.42	11.29	0.13	13.22	13.53	-0.31
10.42	10.23	0.19	11.97	12.01	-0.04
10.82	10.53	0.29	13.22	13.37	-0.15
12.47	12.28	0.19	12.92	13.16	-0.24
10.42	10.18	0.24	11.27	11.19	0.08
10.27	9.95	0.32	10.67	10.65	0.02
11.57	11.26	0.31	14.17	14.35	-0.18
14.07	13.73	0.34	12.07	12.09	-0.02
13.42	13.03	0.39	12.52	12.48	0.04
9.92	9.74	0.18	13.17	13.49	-0.32
12.27	12.02	0.25	11.87	12.07	-0.20
10.32	10.23	0.09	10.12	10.22	-0.10
10.02	10.17	-0.15	11.02	11.23	-0.21
11.72	11.86	-0.14	13.32	13.27	0.05
				Overall mean	-0.02
				SD	0.21

APPENDIX G
PITCH LENGTH EXTRAPOLATION

The focus of the research was on under-10 and under-11 players but at the request of the ECB further data were collected from older players in order to provide some guideline pitch lengths for other age groups.

Ten seam bowlers who had played under-12 or under-13 cricket in the previous season were nominated by their county managers as the best in their age groups and agreed to take part. Ethical clearance was obtained from the University and informed consent obtained from the participants and their parents.

Each player bowled 24 deliveries at the same indoor facility used for the data collection reported in Chapter 4. Ball speed at release was recorded using a Trackman radar-based ball flight tracking device from which median and maximum ball speeds for each bowler were then determined. To these data were added the median and maximum ball release speeds from the 24 deliveries recorded by each of the county bowlers who participated in the study reported in Chapter 4, giving data for 24 bowlers in total, ranging in age from 9.2 years to 14.3 years on the days of data collection (Table G.1).

Linear regressions between age in days and both median and maximum ball release speeds were performed from which median (r^2=0.78) and maximum (r^2=0.71) ball speeds for 9, 11 and 13 year old boys were calculated. The good length figure determined in Chapter 5 based on top order county under-10 batters was scaled with respect to mean stature to give an adjusted good length figure for each age group and the model described in Chapter 6 was applied to calculate new pitch lengths based on both estimated median and maximum ball speeds (Table G.2).

Table G.1. Player age and ball release speed.

	Age		Ball release speed	
	in years	in days	Median ($m.s^{-1}$)	Maximum ($m.s^{-1}$)
1	14.3	5205	29.2	30.2
2	14.2	5193	29.4	30.3
3	14.1	5147	27.2	28.0
4	14.0	5112	26.1	26.4
5	13.6	4956	26.3	26.6
6	13.5	4936	28.2	29.3
7	13.2	4821	25.3	26.1
8	12.9	4712	22.2	22.8
9	12.8	4659	24.7	25.5
10	12.7	4648	26.4	26.9
11	11.1	4044	21.2	22.3
12	11.0	4035	20.2	20.9
13	11.0	4031	23.7	24.8
14	11.0	4020	22.2	23.1
15	11.0	4014	21.3	22.2
16	10.9	3995	20.5	21.6
17	10.9	3979	22.7	23.4
18	10.7	3904	23.3	23.7
19	10.7	3894	21.4	22.7
20	10.5	3848	20.7	21.5
21	10.5	3845	23.2	24.8
22	10.5	3843	21.6	22.5
23	9.9	3634	21.8	23.6
24	9.2	3355	20.1	21.4

Table G.2. Age group pitch length based on median and maximum age group ball release speeds.

Age group	Ball release speed ($m.s^{-1}$)		Good length	Pitch length
Under-9	Median	19.0	5.6 yd/5.1 m	15.1 yd/13.8 m
	Maximum	20.2		15.4 yd/14.1 m
Under-11	Median	22.3	6.0 yd/5.5 m	16.7 yd/15.3 m
	Maximum	23.3		17.0 yd/15.5 m
Under-13	Median	25.6	6.5 yd/6.0 m	18.7 yd/17.1 m
	Maximum	26.4		18.9 yd/17.3 m

Rounding these figures up to the nearest half yard or metre, initial recommendations were made to the ECB regarding pitch lengths junior age group cricket (Table G.3).

Table G.3. Pitch length recommendations

Age group	Pitch length	
Under-8 and 9*	15.5 yd	14.0 m
Under-10 and 11	17.0 yd	15.5 m
Under-12 and 13	19.0 yd	17.5 m
Under-14+	full length pitch	

* Under-8 and 9 **softball** cricket recommendation would be 15 yards or 13.5 m.