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The effect of coaching intervention on elite fast bowling technique over a two year period

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Abstract

Fast bowling in cricket is an activity that is well recognised as having high injury prevalence. Further, there has been debate regarding the most effective fast bowling technique. Therefore, coaching interventions to alter bowling technique with the aim of decreasing the risk of lower back injury and increasing ball speed remain a priority in the sport. Selected kinematics of the bowling action of 14 elite young fast bowlers were measured using an 18 camera Vicon Motion Analysis system before and after two-year coaching interventions that addressed specific element(s) of fast bowling technique. Mann-Whitney tests were used to determine whether any changes in kinematic variables occurred pre- and post-intervention between those who had the coaching interventions and those who didn't. The coaching interventions, when applied, resulted in a more side-on shoulder alignment at back foot contact (BFC) ($p=0.002$) and decreased shoulder counter-rotation ($p=0.001$) however, there was no difference in the degree of change in back and front knee flexion angles or lower trunk side-flexion. This study has clearly shown that specific aspects of fast bowling technique are changeable over a two-year period in elite level fast bowlers and this may be attributed to coaching intervention.

Key words: fast bowling technique, cricket, coaching

Introduction

The game of cricket, whilst contested over time periods of between one and five days, is basically a contest between bowlers who deliver the ball and batsmen who hit the ball with the aim of scoring runs. Whilst attempting to dismiss the batting side, the fielding team may have at its disposal; fast bowlers (who deliver the ball between approximately 140 and 155 km/hr (39 to 43m/s), and two varieties of spin bowlers (off-spin and leg-spin). Fast bowling at the elite level is a dynamic sporting activity that requires athletes to run up and repeatedly deliver the ball. In the case of the game's longest version, Test cricket, this may occur up to approximately 180 times during a day's play.

Cricket is generally considered a relatively low-injury sport with overall injury prevalence rates being low at around five percent of elite players being unavailable to play due to injury at any given time (Orchard *et al.*, 2006, Mansingh *et al.*, 2006, Stretch, 2003, Newman, 2003). However, fast bowlers in cricket have injury rates comparable to contact sports such as Australian Rules football and the Rugby football codes. The injury that has consistently accounted for the most lost playing time is lower back stress fracture (Orchard *et al.*, 2006, Newman, 2003, Ranson *et al.*, 2008a). Side strains, (tear of the abdominal oblique muscles) (Humphries and Jamison, 2004) and repetitive micro-trauma injuries to the knee,

leg and ankle are also relatively prevalent, particularly on the side of the body opposite to the bowling arm.

Fast bowlers can be classified as having one of four action types; they being the front-on, midway, side-on and mixed actions (Portus *et al.*, 2004, Ranson *et al.*, 2008b). The use of a mixed action type, characterised by a large shoulder counter-rotation between back foot contact (BFC) and front foot contact (FFC) during the delivery stride, has been previously associated with lower back injury and the appearance of abnormal radiological features (Burnett *et al.*, 1996, Elliott *et al.*, 1993, Elliott *et al.*, 1992, Foster *et al.*, 1989, Portus *et al.*, 2004) although a causal relationship between shoulder counter-rotation and lower back injury has yet to be established.

When examining the pathomechanics of low back injury in fast bowlers researchers have examined trunk kinematics during the delivery stride. Large amounts of trunk side-flexion have recently been associated with a history of lower back pain in elite female fast bowlers (Stuelcken *et al.*, 2008). Further, in elite senior male fast bowlers, those who suffered a lumbar stress injury within a year of motion analysis testing had non-significantly larger lower trunk extension during the front foot contact phase of the delivery stride (Ranson *et al.*, 2008a).

The amount of ball speed that can be generated is a key weapon in the fast bowler's arsenal as it reduces batters' reaction time. The amount of flexion of the knee during the FFC phase of the delivery stride has been linked to velocity of the delivery with most faster bowlers having a relatively extended (straight) front knee (Portus *et al.*, 2004, Foster *et al.*, 1989). However, whilst performance benefits may be derived from an extended front leg at FFC this feature of the bowling action has also been linked to low back injury (Portus *et al.*, 2004).

One of the aims of coaching is to change the athlete's technique, in order to improve performance and minimise the risk of injury. However, there are few examples in sport where quantitative evidence has been produced to objectively assess the efficacy of such interventions (Grimshaw and Burden, 2000, Dallam *et al.*, 2005, Winchester *et al.*, 2005). The lack of such studies may be due to factors such as; inability to obtain a sufficiently large, homogenous group of athletes, a lack of access to motion analysis equipment and the testing environment for the athlete to perform with sufficient ecological validity. In cricket there have been only two studies that have investigated the efficacy of fast bowling technique modification, both investigating groups of young fast bowlers with a mean age of 13 years (Elliott and Khangure, 2002, Wallis *et al.*, 2002). In the study by Elliot and Khangure (2002), bowlers participated in an initial half day coaching clinic and six small-group coaching sessions conducted over a three to four year period. The study found that coaching interventions were successful in reducing shoulder counter-rotation during the delivery stride. Wallis *et al.*, (2002) used a bowling harness connecting the lower trunk to the front arm which facilitated greater alignment of the shoulders and pelvis at back foot contact but did not alter other aspects of trunk movement such as the degree of shoulder counter-rotation, trunk extension and side-flexion during the delivery stride. It has yet to be determined whether older, elite level fast bowlers with highly developed bowling actions through years of playing and training, are amenable to alterations in specific aspects of bowling technique.

When attempting to change an athlete's technique, coaches will use tailored interventions for the athletes they coach as there is no logical reason to address elements of technique that don't require change. Furthermore, coaches need to make changes to key elements of technique without changing their natural flair and aspects of technique which may have made them successful in the first place. Knowledge of the changeability of this

highly complex motor skill in elite level bowlers may give some insight into the ability of coaching to alter technique characteristics.

Therefore, the aim of this study was to determine whether two-year coaching interventions resulted in the alteration of specific elements of fast bowling technique. This study was conducted in a group of elite fast bowlers and aimed to improve the kinematics of the bowling action relating to; risk factors related to low back injury and increases in ball speed.

Methods

Participants and Protocol

Participants in this study were 14 members of the England and Wales Cricket Board Elite Fast Bowling Group. The mean age, height and mass of participants at the time of initial testing was 18.5(\pm 2.3) years, 190(\pm 6) cm and 82(\pm 5) kg respectively. The mean age, height and mass of participants at the time of follow-up testing was 20.5 (\pm 2.3) years, 192(\pm 7) cm and 86(\pm 6) kg respectively. To be included in the study participants needed to have been identified by the National Lead Fast Bowling Coach as having strong potential to play for England, or be a current member of the England U19 or senior men's team.

Participants underwent baseline testing late in the summer season (August/September) of either 2005 or 2006, having follow-up testing in either 2007 or 2008 respectively. Both baseline and follow-up testing involved biomechanical analysis (Vicon Motion Analysis system, OMG Plc, Oxford UK) of bowlers delivering the ball off a full run-up in a purpose built indoor cricket facility. After baseline testing, coaching interventions for participants (described below in the 'Coaching Interventions' section of the Methods) addressing elements of technique that were deemed to require change were applied over a two year period. Approval for the study was gained from the local area ethics committee.

Kinematic Data Collection

An 18 camera Vicon Motion Analysis System (OMG Plc, Oxford UK) operating at 300 Hz was used to capture a static trial and six fast bowling trials for each bowler. These trials were maximum velocity deliveries that pitched in an area designated as a good line and length by a qualified fast bowling coach. All baseline and follow-up testing were conducted in an indoor practice facility which allowed the subjects to bowl with their normal length run-up on a standard size artificial cricket pitch. Cameras were positioned around the bowling crease to cover a 9 m \times 3 m \times 3 m volume which was wand calibrated prior to data collection. Prior to testing subjects were given adequate time for their routine pre-bowling warm-up activities which included several warm-up deliveries.

Thirty-one spherical reflective markers, 14 mm in diameter, were attached to the participants in order to define shoulder, lower trunk, pelvic, thigh and shank motion. Markers were positioned by trained researchers, following a set of guidelines, and located near bony landmarks or on the mid-line of segments. A square of reflective tape (1.5 cm \times 1.5 cm) was also fixed to one side of the cricket ball to allow the instant of ball release and the ball velocity to be determined.

Kinematic Data processing

Three-dimensional marker locations were reconstructed and processed using the Vicon Workstation and BodyBuilder (OMG Plc, Oxford UK) software and all six bowling trials were manually labelled before selecting the best three (maximum velocity trials with minimal marker loss) of each bowler for further analysis along with the static trial.

The knee and ankle joint centres were calculated from a pair of markers placed across each joint such that the midpoint of each pair of markers coincided with the corresponding joint centre. The hip joint centres were calculated using the ‘hip joint centring algorithm’ from markers placed over the left and right anterior superior iliac spine and the left and right posterior superior iliac spine (Davis *et al.*, 1991). Lower trunk and pelvis motion was calculated from the four markers used to define the hip joint centres plus markers placed over the xiphoid process at the distal end of the sternum and the spinous processes of T10 and L1 (Ranson *et al.*, 2008b).

Local reference frames in the thigh, shank, upper arm, lower trunk and pelvis segments were defined from the markers placed on each segment. The origin of each reference frame was placed at the lower joint centre of the segment when the bowler stood in the anatomical position with the z-axis pointing upwards along the longitudinal axis of the segment, the x-axis pointing to the subject’s right (flexion-extension axis of the joint) and the y-axis pointing forwards. Cardan angles (with X as the lateral axis, Y as the frontal axis, and Z axis as the longitudinal axis) were then used to quantify knee extension (0° = straight with positive angles indicating knee flexion) and lower trunk flexion-extension / side-flexion / axial rotation (0° , 0° , 0° for a neutral upright position). In addition, shoulder alignment was determined by projecting the 3D alignment of the left and right shoulder joint centres onto a horizontal plane (180° = side-on, 270° = shoulders aligned with the bowling crease); the pelvic alignment was determined by projecting the x-axis of the pelvic reference frame onto a horizontal plane (180° = side-on, 270° = pelvis aligned with the bowling crease) and the pelvic to shoulder separation angle was defined as the shoulder alignment angle minus the pelvic alignment angle (Ranson *et al.*, 2008b). In order to smooth the time histories of each kinematic descriptor quintic splines were fitted (Wood and Jennings, 1979, Yeadon and King, 2002).

Kinematic Data Reduction

Shoulder counter-rotation was determined by subtracting the minimum (most side-on) shoulder alignment angle from the shoulder alignment angle at back foot impact (the first frame at which the back foot came into contact with ground during the delivery stride). Bowlers with greater than 30° shoulder-counter rotation were classified as having a mixed action and bowlers with less than 30° shoulder counter-rotation were classified as having a non-mixed action (Portus *et al.*, 2004, Ranson *et al.*, 2008b). The maximum lower trunk extension, contralateral side-flexion and ipsilateral rotation utilised during the delivery stride of fast bowling were also calculated. The knee angle at initial contact, along with the amount of knee flexion followed by the amount of knee extension were calculated for both the back foot (Figure 1) and front foot contact (Figure 2) phases of the delivery stride.

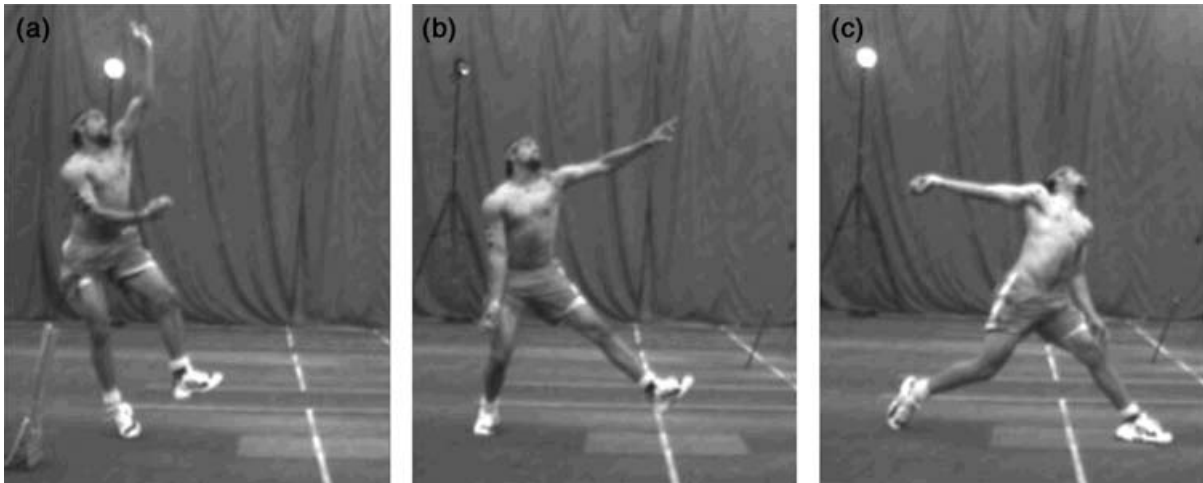


Figure 1. The back knee angle; a. at back foot contact b. at maximum flexion and c. at maximum extension prior to back foot lift off.

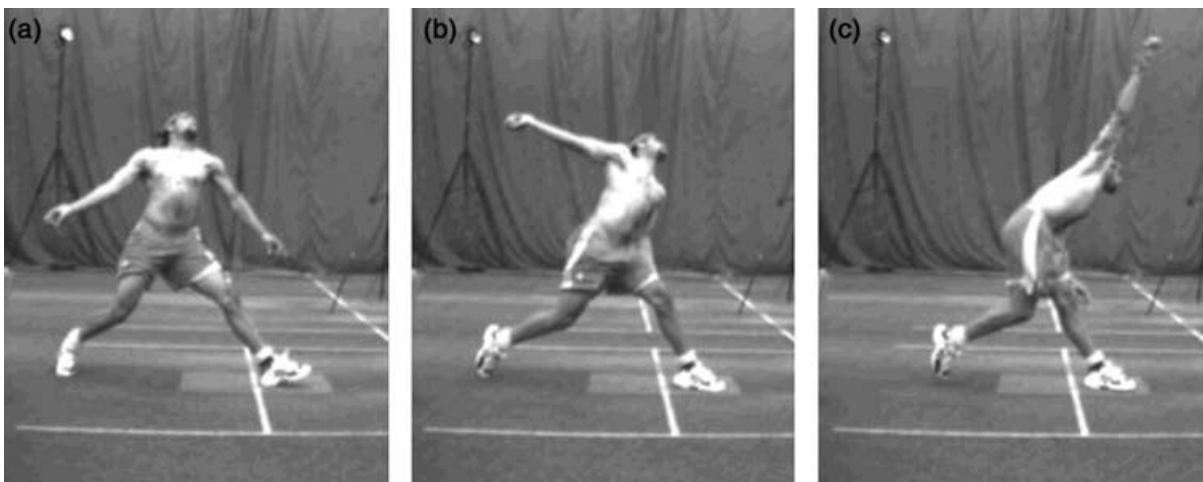


Figure 2. The front knee angle; a. at front foot contact b. at maximum flexion and c. at maximum extension.

Coaching Interventions

Following initial testing, technique reports were produced using Vicon Polygon (OMG Plc, Oxford UK) software. These electronic reports contained data and annotations regarding each bowler's shoulder alignment, lower trunk angles, and, back and front knee angles and during the delivery stride. Reports were supplemented by animation and high-speed video footage and included recommendations for technique improvement, including examples of drills and practice sessions that were developed by the ECB National Lead Fast Bowling coach. Any suggested technique modifications and methods for achieving them were explained to, and agreed upon, by both the cricketer and the fast bowling coach from their County team. Remediation, utilising coaching techniques such as verbal feedback, video feedback and part drills (exercises focused on specific part components of the delivery stride) were instituted during both Club and ECB Elite Fast Bowling Group coaching sessions over the ensuing two years. No control was provided over the amount of intervention provided by coaches, however, participants undertook an average of at least two technical bowling sessions per week during the two-year study period.

Due to variable amounts of coach contact time and as coaches from different programmes (ECB and various county clubs) were involved, specific and detailed prescription of coaching methods was not considered appropriate. However, key coaching principles were agreed upon for each of the following areas for technique modification; improved shoulder and pelvic alignment at BFC (which in eight cases involved those bowlers with a very front-on shoulder alignment and high shoulder counter-rotation achieving a more Midway shoulder alignment at BFC), less back and front knee collapse (flexion) and more upright FFC trunk alignment (less side-flexion).

Of the 14 bowlers who participated in the study, not all were provided with specific areas of technique modification (Table 1). For the eight bowlers with whom it was agreed that they might benefit from a less open (front-on) shoulder alignment at BFC, the coaching language encouraged them to maintain an “upright, compact, position at BFC” with the shoulders and pelvis more closely aligned.

Nine of the bowlers were considered to have excessive collapse (flexion) of the back knee, possibly reducing momentum carried through the delivery stride. An example of a coaching intervention used to address both BFC shoulder alignment and back knee collapse was a plyometric type drill involving repetitions of hops over five low hurdles placed approximately 50cm apart. Whilst maintaining the desired BFC trunk and pelvic alignment participants were encouraged to land with the back knee in a relatively straight (extended) posture and maintain a feeling of staying ‘tall’ and ‘driving’ forward off their back leg following a relatively short contact time.

The main coaching points for those who were deemed to potentially benefit from having either a more extended FFC knee posture or less front knee flexion (nine bowlers), were encouraged to feel that they were “going up and over the front leg”, again “staying tall”. An example of one of the nine bowlers considered to have potentially injurious and performance limiting amounts of trunk side-flexion is shown in figure 3. Figure 4 illustrates a correction drill using a row of intervention poles placed just to the left of the bowler during the delivery stride which were designed to give visual and kinaesthetic cues re-enforcing verbal coaching cues to maintain a ‘tall’ (less side-flexed) posture during FFC and avoiding “falling away” of the body. The emphasis during all coaching was on always being “dynamic and powerful” throughout the delivery stride.



Figure 3. An example of a bowler considered to have potentially injurious and performance limiting amounts of trunk side-flexion during the front foot contact phase of the delivery stride.

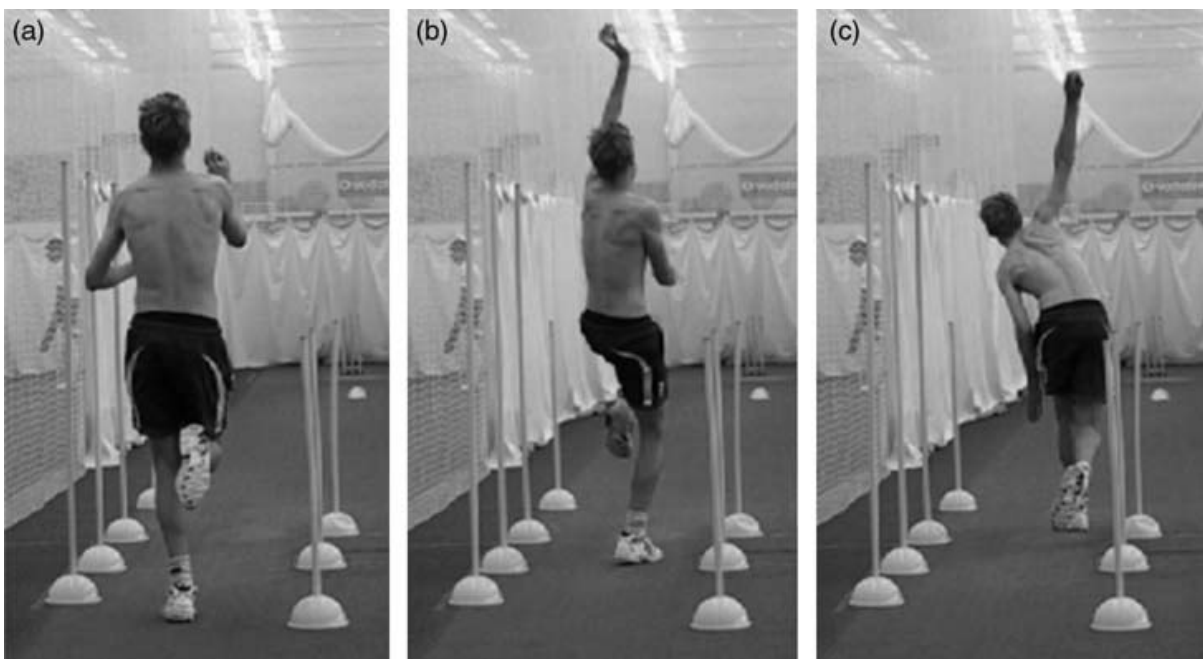


Figure 4. An example correction drill, using a row of intervention poles placed just to the left of the bowler during the delivery stride, designed to reduce the amount of trunk side-flexion during the front foot contact phase of the delivery stride.

Table 1. Matrix of area/s of coaching intervention for each subject.

Subject	More Side-on	Less Back Knee Flexion	Less Front Knee Flexion	Less Lower Trunk Side-flexion
1	-	-	-	Coached
2	-	Coached	Coached	Coached
3	Coached	-	Coached	Coached
4	Coached	Coached	Coached	-
5	Coached	-	Coached	-
6	Coached	Coached	-	Coached
7	-	-	-	Coached
8	Coached	Coached	Coached	Coached
9	-	Coached	Coached	Coached
10	-	Coached	-	-
11	Coached	Coached	Coached	Coached
12	Coached	Coached	-	-
13	-	Coached	Coached	Coached
14	Coached	-	Coached	-
Total	8	9	9	9

Statistical Analysis

Firstly, the inter-trial reliability of the kinematic data was assessed using Intra-Class Correlation Coefficient (ICC) and the Standard Error of Measurement (SEM) (Norton *et al.*, 2000). There was very good between-delivery reliability for all kinematic variables with the mean ICC for initial testing being 0.91 (range 0.74 – 0.98) and a mean SEM of 2° (range 1° – 4°). For the follow up testing the mean between delivery ICC was 0.89 (range 0.74 – 0.98) whilst the mean SEM was 2 ° (range 1 – 5°). Therefore, the three trials selected for each bowler were averaged to provide representative data.

Due to the relatively small size of the data set in this study non-parametric statistical methods were utilised as they do not require any assumptions regarding normality or large sample sizes. Therefore, Wilcoxon signed ranks test were used to determine whether differences existed between initial and follow-up testing across all subjects for all variables. Mann-Whitney tests on the difference from pre and post-testing between the sub-groups who did and didn't receive coaching interventions were then used to determine whether the interventions had an effect on selected kinematic variables. Statistical testing and graphing were carried out using Microsoft Excel and the Statistical Package for Social Sciences V15 (SPSS Corporation, USA). Significant differences were considered to exist at $p < 0.05$.

Results

On initial testing, 13 out of the 14 subjects (93%) were classified as having a mixed action as they had greater than 30° of shoulder counter-rotation. At the two-year follow-up testing, the number of subjects classified as having a mixed action reduced to nine (64%) with four subjects reducing their shoulder counter-rotation to less than 30° allowing them to be classified as Midway. The bowler who made the most dramatic change to their shoulder alignment at back foot contact (285° at initial testing to 214° at follow-up) is shown in Figure 5. The associated reduction in shoulder counter-rotation was 69° to 10°.

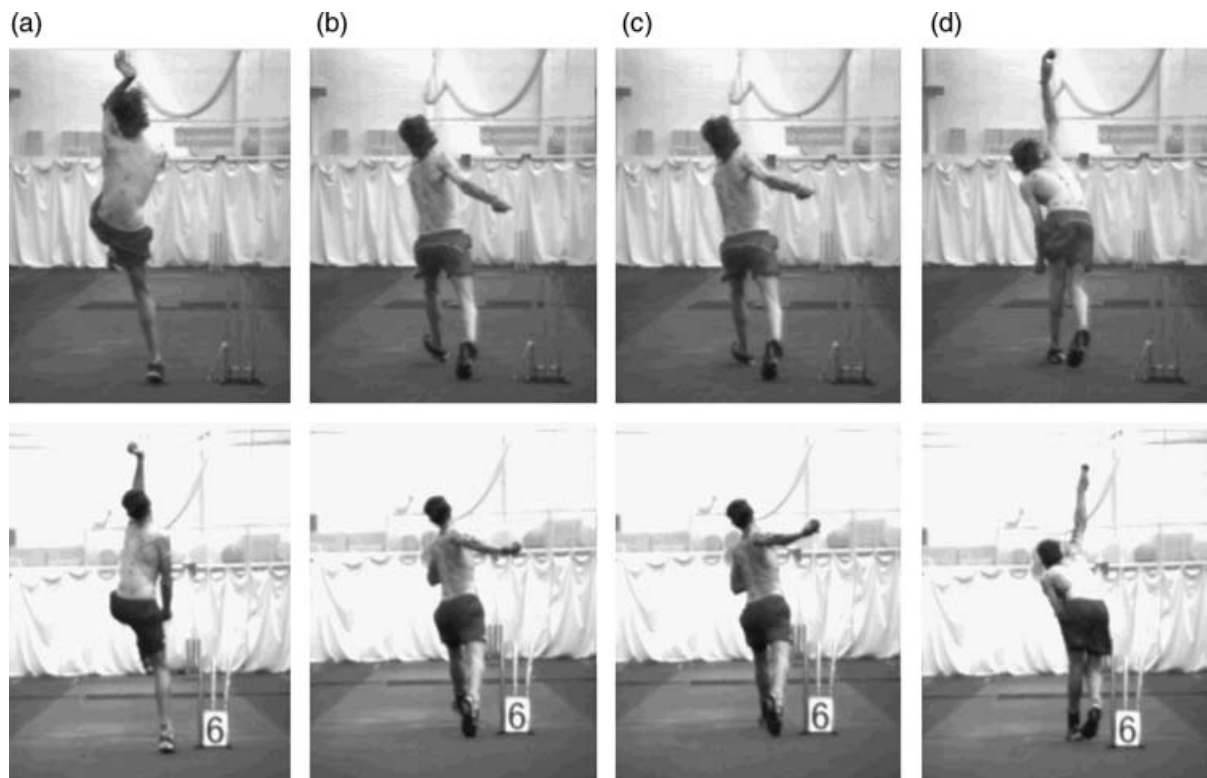


Figure 5. Example of a bowler who changed his shoulder alignment at back foot contact from front-on at initial testing (upper images a and b), to midway two years later (lower images a and b).

Across the entire sample there was a mean decrease in both shoulder alignment at BFC ($p = 0.007$) and shoulder counter-rotation ($p = 0.004$) between the initial and two-year follow-up testing. There was also a decrease of 4° in knee flexion angle at BFC ($p = 0.018$) and a 4° increase in knee flexion angle at FFC ($p = 0.018$) (Table 2) and a 3 mile per hour increase in ball velocity ($p = 0.030$).

Table 2. Mean (SD) shoulder alignment, back knee, front knee, lower trunk angles and ball velocity for all participants ($n=14$) at initial and two year follow-up testing. $^\circ$

Variable		Initial Testing Mean (SD)	Follow-up Mean (SD)	p -value
Shoulder Alignment ($^\circ$)	Shoulder alignment @ BFC	243 (19)	231 (12)	0.007
	Shoulder counter rotation	45 (15)	34 (12)	0.004
Back Knee ($^\circ$)	Angle at BFC	38 (8)	34 (9)	0.018
	Flexion	26 (10)	28 (10)	0.144
Front Knee ($^\circ$)	Angle at FFC	11 (9)	15 (4)	0.018
	Flexion	15 (13)	19 (13)	0.105
Maximum Lower Trunk Motion ($^\circ$)	Extension	0 (7)	4 (10)	0.049
	Contralateral Side-Flexion	34 (7)	33 (6)	0.246
	Ipsilateral Rotation	29 (9)	27 (8)	0.307
Ball Velocity (km/hr)		119 (6)	126 (6)	0.03

Significant values shown in bold

Intervention (Coaching) and No Intervention Group Comparisons

The mean and individual change in shoulder alignment angle at Back Foot Contact and Shoulder Counter-Rotation for both the coaching intervention and no intervention groups is shown in Figure 6. There was a between-group difference in the magnitude of change in shoulder alignment at Back Foot Contact (21° in the coaching intervention group versus 0° in the no intervention group, $p = 0.002$), and Shoulder Counter-Rotation (20° in the coaching intervention group versus 0° in the no intervention group, $p = 0.001$).

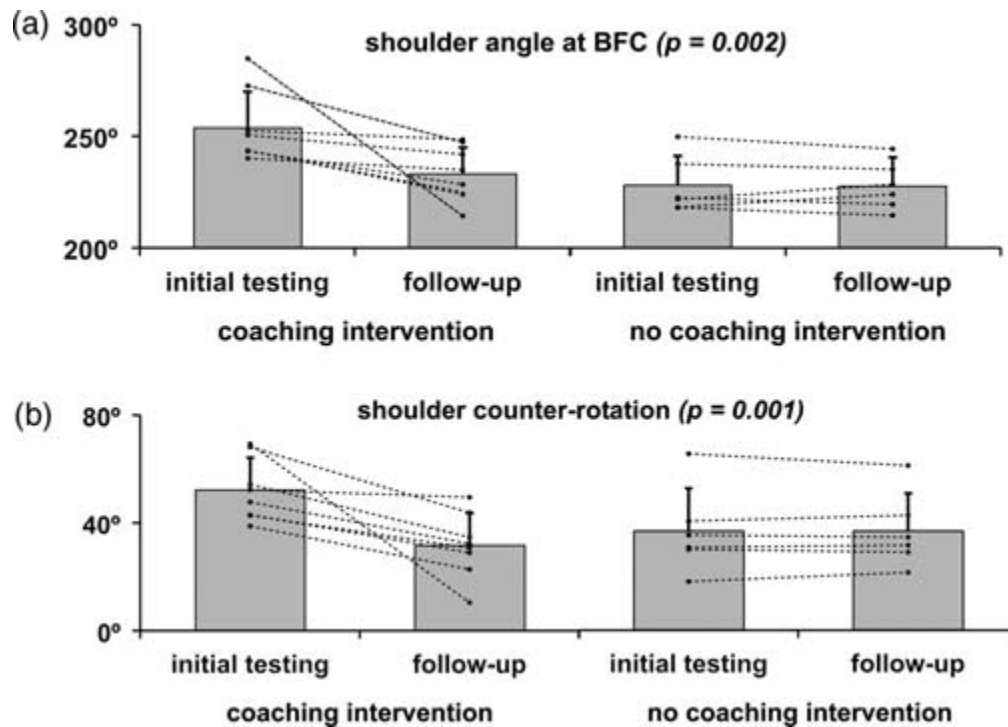


Figure 6. Mean group and individual a) Shoulder alignment at Back Foot Contact and b) Shoulder counter-rotation at initial testing and at two year follow-up in subjects who had i) coaching intervention to reduce the shoulder alignment angle at BFC ($n = 8$) and ii) no coaching intervention ($n = 6$).

There was no between-group difference in both the magnitude of change in Back and Front Knee Angle at BFC and the amount of Back and Front Knee Flexion during the delivery stride (Tables 3 and 4). There was also no difference in the magnitude of change in Lower Trunk Side-Flexion between the coaching and no intervention groups (Table 5).

Table 3. Back knee angle at back foot contact and amount of back knee flexion for coaching intervention and no-intervention groups.

Group	Year	Back Knee Angle at Back Foot Contact				Back Knee Flexion			
		Mean	SD	Mean Difference	<i>p</i> -value	Mean	SD	Mean Difference	<i>p</i> -value
Intervention (n = 9)	Initial	41	8	5	0.226	22	10	-3	0.332
	Follow-up	36	10			25	12		
No Intervention (n = 5)	Initial	33	5	2		32	7	-1	
	Follow-up	31	7			33	5		

Table 4. Front knee angle at front foot contact and amount of front knee flexion for coaching intervention and no-intervention groups.

Group	Year	Front Knee Angle at Front Foot Contact				Front Knee Flexion			
		Mean	SD	Mean Difference	<i>p</i> -value	Mean	SD	Mean Difference	<i>p</i> -value
Intervention (n = 9)	Initial	14	8	-4	0.358	20	13	3	0.072
	Follow-up	18	3			17	15		
No Intervention (n = 5)	Initial	5	7	-6		5	3	-1	
	Follow-up	11	2			6	6		

Table 5. Lower trunk side-flexion for coaching intervention and no-intervention groups.

Group	Year	Mean	SD	Mean Difference	<i>p</i> -value
Intervention (n = 9)	Initial	39	5	2	0.247
	Follow-up	37	6		
No Intervention (n = 5)	Initial	29	6	0	
	Follow-up	29	4		

Discussion

Whilst there has been previous evidence that younger fast bowlers can alter kinematic variables such as shoulder counter-rotation via occasional intervention (Elliott and Khangure, 2002) there has yet to be evidence that older, elite level fast bowlers with highly developed bowling actions can change specific aspects of bowling technique. Therefore, the aim of this study was to determine whether two-year coaching interventions resulted in the alteration of certain key elements of fast bowling technique thought to be related to low back injury risk and generation of ball speed.

The use of a mixed type action characterised by a large degree of shoulder counter-rotation has previously been associated with low back injury in fast bowlers (Burnett *et al.*, 1996, Elliott *et al.*, 1992, Foster *et al.*, 1989, Portus *et al.*, 2004) and therefore, the identification and remediation of excessive shoulder counter-rotation has been a focus of fast bowling coaching (Elliott and Khangure, 2002). Previous studies have shown a relationship between the shoulder angle at BFC and the degree of shoulder counter-rotation (Portus *et al.*, 2004, Ranson *et al.*, 2008b, Portus *et al.*, 2000) such that bowlers with more front-on shoulder alignment at BFC generally having greater shoulder counter-rotation. In this study it was demonstrated that coaching interventions aimed at producing a more side-on alignment could significantly reduce shoulder alignment angle at back foot contact with a corresponding reduction in shoulder counter-rotation. These findings support those of previous investigators who have used coaching (Elliott and Khangure, 2002) and a back harness (Wallis *et al.*, 2002) to successfully reduce shoulder counter-rotation in fast bowlers.

The specific pathomechanics of lower back injury and abnormal radiographic findings in fast bowlers, particularly the highly prevalent non-bowling arm side lumbar stress injuries (Engstrom and Walker, 2007, Gregory *et al.*, 2004) are thought to be related to repeated end-range lower trunk side-flexion, rotation and extension typically adopted during the front foot contact phase of the delivery stride (Burnett *et al.*, 1998, Elliott, 2000, Ranson *et al.*, 2008b). Although the degree of shoulder counter-rotation and the number of mixed action bowlers was reduced over the two year period of this study there was no change in the maximum levels of lower trunk side-flexion, rotation and extension adopted by the participants. This may be due to the fact that between the shoulder girdle and the lower trunk are a number of anatomical structures that effectively dissipate the movement caused by shoulder counter-rotation. These are interesting findings which may have application to intervention programs that attempt to decrease the high rates of stress fractures which result in a large amount of lost playing time (Ranson *et al.*, 2008a), and should be the subject of future investigations.

Even though it was not a specific coaching point, across the cohort as a whole there was a small but significant increase in the maximum lower trunk extension. This greater trunk extension may have been one of the factors which may have contributed towards increased ball speed, possibly via enhanced trunk flexion torque production due to greater trunk flexor muscle activation and stretch shortening. However, coaches need to be careful about encouraging greater trunk extension during FFC as it is likely to place greater stress on the vulnerable posterior bony elements of the lower spine (Chosa *et al.*, 2004).

Having an extended (relatively straight) front knee during FFC has been previously associated with an ability to produce faster ball speeds (Loram *et al.*, 2005, Portus *et al.*, 2004). This may be due to a more efficient kinetic energy transfer to the ball, as the body rotates over a 'braced' front leg. Contrary to the aim of the intervention, the bowlers in this study displayed a less extended (straight) front knee position at FFC on follow up testing. However, there was no difference in either the degree of change in front knee angle or total front knee flexion between the participants who were and were not coached to achieve a straighter front knee. The ball velocity increased an average of five km/hr (1.4m/s) over the

period of the study and it seems possible this had more to do with the physical maturation of this group of elite young fast bowlers who grew significantly taller and heavier, than the coaching interventions (Pyne *et al.*, 2006). This increased size may also have been a factor in the slightly more flexed front foot contact knee posture.

Whilst this study was a unique, real-world study there are a few limitations that need to be acknowledged when considering the findings. Firstly, due to the long duration of the project and widespread location of the participants it was not possible to accurately monitor strength and conditioning inputs which may also have effected aspects of technique such as the degree of knee flexion and trunk side-flexion during the delivery stride. However, it could be assumed that along with height and mass, participant lower limb strength and trunk control is likely to have progressed over the two year duration of the study as both the National and County Squads they were members of conducted year round strength and conditioning programmes, supervised by full time professional strength and conditioning staff. A recommendation for future coaching programmes and research projects is that strength and conditioning work is aligned to and integrated with technique goals and coaching programmes. Secondly, although every effort was made to ensure markers were positioned in the same locations in both testing sessions, some variation in positioning was inevitable. This may have had a small influence on the magnitude of the joint angles recorded. However, due to the random nature of this error, its effect on the data as a whole was likely to be minimal. Finally, the relatively uncontrolled volume and specificity of coaching drills is a possible limitation of the study. However, the individualised coaching programme employed closely matches the 'real world' coaching environment for this level and age of athlete, adding to the ecological validity of the project.

Small sample sizes are a perennial problem when investigating elite sporting sub groups such as elite young fast bowlers in cricket. However, the participants in this study represented a large proportion of the UK's best young fast bowlers with those who didn't receive coaching for a specific aspect of technique effectively acting as control participants. The results of this study are only applicable to young elite fast bowlers who may be more amenable to technique change than older professional fast bowlers, who are also commonly coached with the aim of altering technique.

Apart from coaches and participants agreeing to follow general principles it was not possible to standardise the amount and quality of coaching intervention delivered, and as previously mentioned, aside from coaching, extraneous variables such as physical development and injury might have had a substantial impact on participants' technique and ball velocity. Future studies should examine the effect of coaching intervention against variables such as lower back injury incidence and the progression of lumbar radiological changes.

Conclusion

This study has clearly shown that specific aspects of fast bowling technique can change in elite players over a two year period and this may be attributed to coaching intervention. However, although factors related to shoulder alignment at the beginning of the fast bowling delivery stride were changed, desired improvements in trunk posture and knee mechanics later in bowling action i.e. during FFC, were not able to be achieved in this group. It may be that good technique in these areas needs to be developed from a younger age with more focused coaching of the trunk and knee mechanics occurring during the FFC phase of the delivery stride. Future studies examining a variety of age groups should examine the effect of coaching intervention on lower back injury incidence and the progression of lumbar radiological changes.

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