

**ECB Regulations for the Review of Bowlers Reported with Suspected Illegal Bowling Actions**  
(Effective 22<sup>nd</sup> March 2015)

**A. Introduction**

1. Nothing contained herein shall override an umpire's responsibility and discretion to apply Law 24.
2. These Regulations will apply to Competitive County Cricket as defined in the Regulations Defining the Qualification of Cricketers with the exception of Minor County Cricket, and to any team participating in First Class County Second XI cricket under the jurisdiction of the ECB (including MCC Young Cricketers, MCC Universities and Unicorns), and to any matches involving an England representative side at any level which do not fall under ICC Regulations. (Competitive County Cricket).
3. In these Regulations references to a Player's County shall refer to the First Class County with whom the Player is registered or contracted at the relevant time or for whom the Player played in the relevant match. Where a Player is not registered or contracted to any County, notifications shall be sent directly to the Player or, with the Player's permission, the PCA.

**B. ECB Panel of Human Movement Specialists**

1. The ECB shall appoint a panel of human movement specialists when required.
2. The members of this panel shall have the credentials, equipment and facilities to conduct analysis of the bowling actions of bowlers in accordance with the ECB Standard Analysis Protocols (Appendix 1 hereto).

**C. Bowling Review Group**

Upon receipt of an application for a Bowling Review Group hearing in accordance with paragraph F below, the ECB shall appoint a Bowling Review Group (BRG) in accordance with the following terms:

1. The BRG shall normally comprise the following persons: The Chairman of the ECB Cricket Committee or his nominee (in the Chair and with the casting vote), the Chairman of the MCC Cricket Committee (or his nominee), a bowling technician nominated by the ECB Performance Director, an ex-international fast bowler, finger spin bowler or wrist spin bowler dependant upon whichever category of bowler is being reviewed, an ex-international umpire, a representative of the PCA and a human movement specialist. The Head of Operations (First-Class Cricket) (or his nominee) shall be an ex-officio member of the BRG. The ECB will nominate individuals to fulfil the following roles as appropriate:

Ex international fast bowler  
Ex international finger spinner  
Ex international wrist spinner  
Ex international umpire  
Human Movement Specialist

2. The Chairman of the BRG shall be responsible for selecting the other members of the BRG in accordance with paragraphs C 3 and 4 below.
3. The human movement specialist shall be appointed from the ECB panel of human movement specialists referred to in paragraph B above. The human movement specialist shall not be the same person as the specialist who conducted the independent analysis referred to paragraph E below.
4. It is preferable that at least one of the BRG shall be a qualified legal practitioner. In the event of the BRG, as appointed in accordance with the provisions of paragraphs C 1 - 3 above, not including a legal practitioner then a legal practitioner shall be appointed to the BRG in an advisory capacity only and he shall not have a vote.
5. The quorum for any hearing of the BRG shall be six persons provided that the Chairman, representative of the PCA and the human movement specialist shall be included therein.

6. No member of the BRG shall have clear associations with the Player or the County of the player who is the subject of the BRG hearing.

#### **D. Reporting Procedure**

If a player is called by an umpire for throwing in accordance with Law 24.2 or is suspected by the umpire(s) for bowling with an action which contravenes Law 24.2 as read with Law 24.3 (an "Illegal Bowling Action"), the following reporting procedure shall apply.

Note: Umpires, in deciding whether to call or report a player as set out above, should use the naked eye viewing the action live and/or on television at normal speed. Slow motion television replays should only be used to confirm initial suspicions.

1. At the conclusion of the match the umpire(s) shall write a report (the Umpires' Report) detailing their concerns about the bowling action of the player (the Player), including, where relevant, whether those concerns relate to the Player's bowling action generally or whether they relate to one or more specific types of delivery, and immediately inform the ECB Head of Operations (First-Class Cricket).
2. Within 5 days (120 hours) of the conclusion of the match in which the Player is reported, the ECB shall furnish the Chief Executive of the Player's County with a copy of the Umpires' Report.
3. If an umpire(s) reports a player who has been analysed previously, whether under these or any predecessor Regulations or under any equivalent ICC Regulations, the umpire(s) shall be shown the reports, and where available image based evidence of that player, and asked whether he wishes to confirm his original report.
4. Should a bowler be 'called' or 'reported' by two different umpires in different matches within a period of 12 months he shall be required to submit to an independent analysis of his bowling action as outlined in paragraph E below. For the avoidance of doubt, if an umpire is appointed to a game in which a bowler is reported, a further report from any game in which he is appointed will not be considered a valid report for the purposes of this condition, regardless of whether that umpire participated in either of those reports. This paragraph will apply regardless of whether either or both reports were in relation to the Player's bowling action generally or any specific types of delivery.
5. Until the receipt by the Chief Executive of the Player's County of the Independent Assessment, the ECB will where possible not make any public comment regarding any Umpires' Report of a Player's bowling action. However, where it is considered necessary in order to address / minimize media/public speculation, at any time after the Chief Executive of the Player's County has been furnished with a copy of a second confirmed Umpires' Report and after the Player has been informed of the situation, the ECB may issue a media release to the effect that the Player has been called or reported twice in a 12 month period and that he will be subject to the Independent Analysis process as set out herein. Where the Independent Assessment of the Player results in a Suspension or Warning as outlined in E8 and E9 then ECB will issue a media release summarising the outcome of the Independent Assessment and the action to be taken by ECB. Where the Independent Assessment does not result in a Suspension or a Warning the ECB must, with the agreement of the Player, issue a media release summarizing the outcome of the Independent Assessment.
6. When reports are made in matches that have been televised or filmed, upon receipt of the Umpires' Report, the ECB will arrange for three copies of the footage of the bowling spells of the Player in the match in question to be produced as soon as possible. Once copies of this footage have been received, the ECB shall forward the County two copies. The County shall retain one copy for its own purposes and the other shall be forwarded to the Player. The third copy shall be retained by the ECB for any Independent Analysis and BRG hearing referred to in paragraphs E and F below. If footage from the matches when the reports were lodged is not available or not of an appropriate quality then the Independent Analysis may analyse other footage of the Player bowling in matches during the previous 12 months. Such footage should be selected following consultation with the Player and/or his County in order to discuss whether any changes have been made to his action since the footage was filmed.

## E. ECB Independent Analysis

If a Player is reported in accordance with paragraph D above, he shall be required to submit to an independent analysis of his bowling action (Independent Analysis) carried out in accordance with the following terms:

1. The Independent Analysis shall be carried out by a member of the ECB panel of human movement specialists referred to in paragraph B above (the Appointed Specialist), appointed by the Chairman of the Cricket Committee. The Appointed Specialist shall not have clear associations with the Player or the Player's County.
2. The Independent Analysis shall be carried out as soon as reasonably possible but in any event within 21 days of receipt by the Player's County of the notice of the second report referred to in paragraph D 2 above.
3. The Independent Analysis shall be carried out in accordance with the ECB Standard Analysis Protocols (Appendix 1 hereto). The Independent Analysis shall take into account the Umpires' Reports. If the Player expresses any concern or complaint regarding the circumstances or conduct of the Independent Analysis, he should make these known to the Appointed Specialist before the conclusion of the Independent Analysis. The Appointed Specialist should make a written note of the relevant concern or complaint which should be agreed with the Player.
4. The ECB shall be responsible for determining the time and place at which the Independent Analysis shall be carried out and shall ensure that the Player, through the Player's County, is given reasonable notice thereof. It is expected that the Player's County Coach or Director of Cricket at the time of the second report will be present at the Independent Analysis. Alternatively or in addition, the Player shall be entitled to be accompanied at all times during the Independent Analysis by a representative.
5. In the event of the Player failing to submit to the Independent Analysis as required above, such failure will be regarded as an admission that he bowls with an Illegal Bowling Action and he shall be immediately suspended from bowling for England and in Competitive County Cricket until such time as he so submits.
6. Within 14 days of the date for the carrying out of the Independent Analysis, the Appointed Specialist shall furnish the ECB with a written report (hereinafter referred to as the Independent Assessment) in the form as set out in the ECB Standard Analysis Protocols. Where the Independent Assessment concludes that the Player employed an Illegal Bowling Action during the Independent Analysis, it should indicate whether the Player employed an Illegal Bowling Action generally or in respect of specific type(s) of delivery only and whether, in the Appointed Specialist's opinion, such conclusion is not inconsistent with the relevant video evidence. Where the Independent Assessment concludes that the Player did not employ an Illegal Bowling Action during the Independent Analysis, it should, where relevant, indicate whether, in the opinion of the Appointed Specialist, the Player's bowling action during the Independent Analysis was materially different to his action in the relevant video evidence (whether generally or in respect of the specific type(s) of delivery (if any) identified in the Umpires' Reports). The Independent Assessment should also include any notes of concerns or complaints of the Player made under paragraph 3 above.
7. Immediately upon receipt of the Independent Assessment by the ECB, the ECB shall furnish the Player's County with a copy thereof.
8. **Subject to paragraph 9 below, in the event that the Independent Assessment concludes either that (i) the Player employed an Illegal Bowling Action during the Independent Analysis and that such conclusion is not inconsistent with the relevant video footage or that (ii) the Player's bowling action during the Independent Analysis was materially different to his action in the relevant video footage, the Player shall immediately be suspended from bowling for England and in Competitive County Cricket until such time as he has submitted to a fresh Independent Analysis in accordance with the provisions as set out in paragraph G below, and in which fresh Independent Analysis it is concluded that he has remedied his action (a Suspension). The Suspension shall become operative from the date of receipt by the Player's County of a copy of the Independent Assessment in accordance with paragraph E 7 above.**

**Note:** The ECB and ICC Standard Analysis Protocol contain reference to a level of acceptable elbow extension. **Should the Independent Assessment conclude that the Player's action exhibits a degree of elbow extension of the bowling arm higher than the said acceptable level; the action of the Player shall be deemed to be an Illegal**

**Bowling Action.** It should be noted that in order for the action to be classified as a legal action, the degree of elbow extension recorded for each delivery shall be within the level of acceptable elbow extension.

9. In circumstances where the Independent Assessment concludes that The Player employed an Illegal Bowling Action or used a materially different bowling action during the Independent Analysis in respect of a specific type of delivery only, the Player will be allowed to continue bowling for England and in competitive County cricket but subject to the warning (Warning) that should he continue to bowl any of the specific type(s) of delivery for which he has been found to have an Illegal Bowling Action, he will run the risk of being reported again. In these circumstances further reports resulting in an Independent Analysis concluding that the Player has employed an Illegal Bowling Action (whether in respect of a specific type of delivery or more generally) will result in the immediate suspension of the Player from bowling for England and in Competitive County Cricket and such suspension shall be considered a second suspension under the provisions of paragraph H below.

**Note:** This is intended to cover the circumstances where a bowler employs a different technique to deliver a specific type of delivery e.g. propelling the ball out of the back of the hand to produce a “googly” or “doosra”. It is not intended to cover the situation where the same basic technique is used to produce a different type of delivery e.g. more effort to produce a “bouncer” or a “yorker”.

10. Throughout the period from the date of any Umpires’ Report which triggers an Independent Assessment up to the date of receipt by the Player’s County of the Independent Assessment, the Player shall be permitted to continue bowling in Competitive County Cricket. At any time throughout this period the Player is subject to being called on the field by the umpire(s) in accordance with Law 24.2 and the consequences of such Law must apply. During this period a further Umpires’ Report will however have no consequence.
11. From the time that the Player’s County is informed of a second confirmed Umpires’ Report within a 12-month period, the Player will be ineligible to represent England at any level until he has undergone an Independent Assessment which does not result in a Suspension.
12. In the event that the Player does not accept the conclusions of the Independent Assessment he shall be entitled to a hearing of the ECB Bowling Review Group (BRG). The conclusions of the Independent Assessment and any Suspension or Warning imposed as a consequence of those conclusions will stand pending the decision of the BRG.

#### **F. ECB Bowling Review Group Hearing**

1. The Player seeking a hearing of the BRG shall lodge with the ECB Head of Operations (First Class Cricket) written notice thereof within 14 days of the date of receipt by the Player’s County of the Independent Assessment. The BRG hearing will be held as soon as reasonably possible but at least within 21 days of receipt by the ECB of the Player’s written notice referred to above.
2. The BRG hearing shall be held in person and not by telephone or video Conference although the BRG may, in its discretion, admit evidence at the hearing in any form.
3. The ECB shall be responsible for arranging the appointment of the BRG in accordance with paragraph C above and for determining in consultation with the Chairman of the BRG the time and place for the hearing. The ECB shall ensure that the Player, through the Player’s County, is given reasonable notice thereof.
4. The Player shall attend the hearing. However, if the Player has received notice of the hearing in terms of clause F 3 and fails to attend the hearing, the hearing may at the absolute discretion of the Chairman of the BRG, proceed in the absence of the Player.
5. The Player shall be entitled to a representative who shall be entitled to attend the hearing.
6. The BRG hearing shall be conducted in accordance with the Principles of Natural Justice.

7. The BRG will consider the following:
  - 7.1 The Umpires' Reports.
  - 7.2 The Independent Assessment together with any image based evidence accompanying such assessment.
  - 7.3 The image based evidence referred to in paragraph D 6 above.
  - 7.4 Any further evidence that the Player and/or his representative wishes to present in the Player's defence. This may include a written report, a verbal submission, any expert evidence and image based evidence.
  - 7.5 Any written or image based evidence that the Player's County wishes to be considered on behalf of the Player.
8. The Player and/or his representative shall be entitled to question any person called to give evidence in the course of the hearing on any issue relevant to the hearing. The members of the BRG shall be entitled to question the Player and/or any person called to give evidence on the Player's behalf.
9. After all the evidence and argument has been presented, the BRG shall adjourn the hearing to deliberate on its decision.
10. The BRG shall reach a decision by a simple majority vote. The Chairman of the BRG has the casting vote.
11. The BRG shall decide on balance of probability whether or not the Player has an Illegal Bowling Action and that (i) the Suspension of, or the Warning to, the Player be maintained, or (ii) the Suspension of, or the Warning to, the Player be lifted or (iii) the Suspension of a Player be lifted but a Warning imposed in respect of a particular type of delivery. The BRG must, in each case, set out the reasons why the decision has been reached, including a summary of the evidence on which the decision was based.
12. The ECB will communicate the decision of the BRG in writing to the Player, through his County, within 48 hours of the hearing being adjourned in accordance with paragraph F 9 above.
13. Subject to the right of the Player to re-assessment in accordance with paragraph G 2 below, the decision of the BRG shall be final and binding.

#### **G Re-assessment of Player's Action**

1. A Player who has been suspended from bowling for England and in Competitive County Cricket under these regulations may be permitted under the supervision of his County and with the consent of the ECB to continue to play 2<sup>nd</sup> XI County Cricket, Minor Counties Cricket and League cricket (subject to the MCCA/League giving approval to this arrangement).
2. Subject to the provisions of paragraph G 5 and paragraph H below, a Player who has been suspended from bowling for England and in Competitive County Cricket under these regulations, may at any time apply to the ECB for a re-assessment of his bowling action.
3. Such re-assessment shall be carried out in the same manner as the Independent Analysis referred to in paragraph E above, save that the purpose of the comparison between the re-assessed action and the action of the Player as employed in the match he was reported shall be to determine the extent, if any, of the improvement to his action.
4. In the event of such re-assessment concluding that the player has remedied his action and that his action is no longer an Illegal Bowling Action the Player's suspension shall be lifted and he shall be permitted to continue bowling in Competitive County Cricket forthwith (and for England assuming that he is not suspended by ICC).
5. The BRG shall have the discretion to specify a fixed period before the expiry of which the bowler shall not be entitled to approach the ECB for a re-assessment of his bowling action in terms hereof. Such discretion shall only be exercised in the instance where an application discloses no rational or coherent grounds for a BRG hearing and the maximum period so specified shall be 1 year.
6. The Independent Assessment resulting from re-assessment will stand in the place of the original Independent Assessment, and the provisions of paragraphs E 7, 8, 9 and 11 and of paragraph F will apply in respect of it.

7. Any player suspended from bowling in international cricket or receiving a warning regarding a particular type of delivery by ICC (including any provisional suspension) will also be deemed to be suspended from bowling or warned against bowling that particular type of delivery in Competitive County Cricket . ECB may in exceptional circumstances permit the Player to continue to play in certain defined competitions within the domestic cricket programme whilst undergoing remedial coaching and / or supervision as ECB deems appropriate. If ICC lifts a suspension on a bowler then any suspension on the bowler imposed by the ECB will also be deemed to have been lifted.

#### **H. Second and Further Suspensions**

In the event of a Player receiving a Suspension or Warning from bowling in Competitive County Cricket under these regulations for a second time within a period of 2 years from the date of the commencement of the first Suspension or Warning, the Player shall be suspended from bowling in Competitive County Cricket for a minimum period of 1 year. Only after the expiry of this 1 year period is the Player entitled to approach the ECB for a re-assessment of his action in accordance with paragraph G above. (See also paragraph E9 above).

#### **I. Costs**

1. The ECB will be responsible for the costs of the first Independent Analysis and Assessment and the first re-assessment under paragraph G (subject to a maximum of one re-assessment within a period of 2 years) of any bowler as well as the costs of the BRG hearing, excluding the costs incurred by the Player to attend thereat.
2. The Player and/or his County shall be responsible for the payment of any costs of representation of the Player and for any subsequent re-assessments carried out at the Player's or County's request.

#### **J. ECB Development of Excellence Programme**

The Performance Director and the Technical Director of Coaching may commission an analysis of any bowler within the England Programme about whom they have concerns regarding the legitimacy of his / her action.

## Appendix 1

### ECB Standard Analysis Protocols

#### Biomechanical Analysis of a Bowling Action

##### 1. Introduction

The ECB has introduced a revised process for the review of bowlers with suspected illegal bowling actions (Bowling Review Process).

In order for the Bowling Review Process to be conducted in a fair and consistent manner the following standard protocols for the collection of data and the assessment and analysis of bowling actions have been introduced.

The overall purpose of the report is to confirm the legality / or not, of the action of the player as used in the match situation. Thus the protocols are provided not only for how the action should be analysed in the laboratory setting, but also highlight the need for a detailed comparison between the action performed during match situations and the bowling action analysed in the laboratory.

It has been determined that it is the degree of elbow extension, as opposed to hyperextension or abduction / adduction that is prohibited. Elbow hyperextension and elbow abduction / adduction are involuntary movements that cannot be controlled by the individual during the bowling action. (See Paragraph 5.3 & Appendix A)

The conclusion of the report should be that having analysed the action in the laboratory and having compared it to the action as used in match situations, in the opinion of the expert, the action used by the bowler is within or exceeds the acceptable levels of elbow extension.

##### 2. Video Footage from Match Situations

Where available the entire bowling spell(s) of the player in the match where the reports were made shall be presented on a master tape. If footage from the matches when the reports were lodged is not available or not of an appropriate quality then the Independent Analysis may analyse other footage of the Player bowling in matches during the previous 12 months.

Where possible the master tape shall be converted to 50HZ / 60HZ (standard television footage is recorded at 25HZ) to enable more accurate evaluation of the player's bowling action in match situations.

Descriptive analysis during the match footage should compare the actions of the bowler e.g. positioning of feet, angle of run up, position of the torso, velocity of arm, velocity of delivery (95% of match speed etc). These comparisons should be clearly presented in the report.

##### 3. Anthropometric Assessment (Both the bowling & non-bowling arms) See Appendix A

**Carry Angle:** The angle between the longitudinal axis of the upper arm and forearm, in the frontal plane. Note: The average range of carry angle for the human population is between 5°-15°.

**Hyperextension Angle:** The angle between the longitudinal axis of the upper arm and forearm, in the sagittal plane. (i.e. beyond full normal extension ): Two measurements are required: a passive measurement, where there is no force applied and a second measurement where 'reasonable' force is applied. When the second measurement for the hyperextension angle is measured, the bowler is required to extend his arm back as far as possible. This is achieved by applying a 'reasonable' force, essentially the body weight of the bowler, leaning on each arm.



**Additional Physical Measurements:** Height, weight and assessment of general mobility of the shoulder, elbow and wrist joints.

**History of Previous Injuries:** A brief history of previous injuries should be determined as an aid in the biomechanical assessment - particular focus should be brought to the elbow and shoulder joints.

#### 4. Bowling Analysis (Indoors – Laboratory conditions)

All biomechanical assessment shall be carried out with the player bowling off his normal full run-up, on a correct length cricket pitch.

A minimum of three synchronised cameras (using optio reflective markers) operating at a minimum of 250 frames per second should be used to collect the data. The cameras and computer to be operated and positioned in appropriate positions to facilitate a subsequent three-dimensional analysis of the shoulder, elbow, wrist and ball.

Video data (50fps) should also be collected in order to allow synchronisation with the 'optio reflective computer animation data'. A minimum shutter speed of 1000Hz is required to prevent blurred images.

Calibration and accuracy procedures must be undertaken in the delivery space prior to data collection. Accuracy analysis should indicate that the 3D methods employed are accurate to within  $\pm 1^\circ$  (Note: A rigid bar (1m in length), with markers representing the shoulder, elbow and wrist ( $180^\circ$ ) can be used in the calibration procedures. The rod must be rotated in the same manner as a bowling arm. This should be repeated using a rigid bar representing a  $160^\circ$  angle. Accuracy analysis should again indicate that the 3D methods employed are accurate to within  $\pm 1^\circ$ ).

Optimal "levels of filter" must be used in the laboratory process. Ideally a laboratory environment using opto-reflective marker system will produce the environment with the least amount of error (Noise) and therefore less filtering can be used. This value or cut off frequency is calculated via the residual analysis method presented by Winter (1990) – (See Appendix B)

Warm up (player's own) – but must include the bowling of a number of deliveries at match pace prior to data collection. The player to have no clothing on the torso, in order to enable the correct marker set to be placed on the bowling arm. (See Appendix C) Automatic digitisation of the marker set will enable joint centres to be determined during each delivery.

In respect of a fast bowler, six 'normal' – good length deliveries, six 'yorkers' and six 'bouncers' must be recorded. Six deliveries of each spin variation for the leg or off spin bowler must be recorded. Standard video cameras should be used to assess the position the ball lands, along with the amount of bounce and turn created with each delivery. This video should also be presented in the report.

Three-dimensional analysis of the bowling arm to begin from 20ms prior to 'arm horizontal' to include, maximum flexion, ball release and 20ms after ball release for each successful delivery.

The UPPER Arm is in the horizontal position in Figure 1b. "The horizontal position" i.e. The upper arm being level with shoulder and parallel to the ground.

The point of release is defined as the FIRST frame the BALL and HAND are NOT in contact. This is important as the exact time (frame – 250Hz) of release can potentially change results by three or four degrees. A marker (a piece of reflective tape) on the ball, a change in velocity of the ball, along with 50Hz video may all help with this process.



Figure 1a: Arm Horizontal – NO



Figure 1b: Arm Horizontal – YES

Every effort must be made to ensure that the player is bowling as close to match pace as possible. This can be measured after each delivery if the equipment is available (Radar Gun), or measured via the 3D data during analysis. If deliveries are not at a suitable speed (so as to represent match conditions) then the data shall be **invalid**.

## 5. Presentation of Results

A summary of the results of each delivery to be presented – graphical or table format.

Three-dimensional analysis of the bowling arm to begin from Back Foot Contact, to include 'arm horizontal', 'maximum flexion', 'ball release' and '20ms after ball release'.

The 'flexion-extension' curve, the 'abduction-adduction' curve and the 'hyperextension' curve should be presented separately. This data should be presented in graphical form.

The six trials for each type of delivery (e.g. Bouncer / Normal Length / Yorker), along with the average should be plotted on the same graph to show conformity (i.e. 3 graphs, one each for the bouncer, normal length and Yorker deliveries).

The average of the different types of delivery (e.g. Bouncer / Normal Length / Yorker) to be displayed along with the standard error reading.

Shoulder, Elbow, Wrist and Ball release speeds to be presented for each delivery.

Stick figure representation, to include pictures of the various key positions to aid in the presentation of the results.

## 6. Acceptable level of Elbow Extension

This should be set at a maximum of 15 degrees 'Elbow extension' for all bowlers and types of deliveries. This specifically refers to extension of the forearm relative to the upper arm to the straight position. Elbow hyperextension or adduction is not included in the 15-degree tolerance threshold. It should be noted that in order for the action to be classified as a legal action, the degree of 'elbow extension' recorded for each delivery should be within the 15 degree limit.

### Appendix A: Movements.

**Flexion** - This movement takes place about a transverse axis and is a description of the movement that occurs when you move your arm forward. It is described as the approximation (moving closer together) of two ventral surfaces of the body e.g. flexing the elbow joint. There are a number of situations where this rule doesn't seem to apply e.g. at the ankle where the terms dorsi and plantar flexion are used to avoid confusion.

**Extension** - This movement is the opposite of flexion; it also takes place about a transverse axis and occurs when you approximate two dorsal surfaces e.g. straightening the elbow.

**Hyperextension** - An abnormal movement beyond the normal limit of extension, such as more than the 180 degrees of extension of the knee or elbow joints.

**Abduction and Adduction** - These movements take place about an antero-posterior axis and occur when the arm is taken sideways away from the body (abduction) and returned from such a position to the side of the body (adduction).

### Appendix B: Filter Level.

When measurements are made using image-based analysis systems (Video and/or Automatic Tracking) they are contaminated with 'Noise' generated during the recording and digitising procedures. The sample signal can be considered to be the sum of the true signal, systematic noise and the random noise. The 'TRUE' signal can never be deduced from the measurements; only the best estimate of the signal.

There have been a number of techniques developed for the reduction of noise, including Butterworth filters, Quintic splines and cross-validated splines. Each of these techniques uses a mathematical function to approximate the data. The precise frequency components of the true signal are rarely known in sports biomechanics and some procedures must be adopted for the determination of the cut-off filter, or other smoothing parameter. The less noise in the system, the closer the raw data will represent the 'TRUE' signal, and the less smoothing will be required.

Ideally a laboratory environment using opto-reflective marker system will produce the environment with the least amount of error (Noise) and therefore a lower filtering value can be used. Optimal "levels of filter" must be used in the laboratory process. This value or cut off frequency is to be calculated for all bowling analysis using the residual analysis method presented by Winter (1990).

Previous work in this area has identified a Butterworth digital filter level of 12 – 14 Hz and a Woltring MSE of 20 – 25 cine appropriate. However a residual analysis, should be conducted for the bowler being analysed to derive the optimum filter level for the current data. Any significant different optimum filter level derived from the above values needs to be well justified and documented. Raw data should be graphed with filtered data and inspected by the expert to ensure the filtered curve closely reflects the raw data.

## **Appendix C: Marker Set**

### **Cricket Upper Limb Model**

The following guidelines are established to ensure conformity of elbow joint data across laboratories. Establishment of joint centres at the shoulder, elbow and wrist joints are therefore integral to this process.

#### **Shoulder Joint**

This joint centre should be determined from the recording of markers anterior, posterior and superior (acromion process) to the "joint centre of rotation". The anterior and posterior markers should be placed such that a line between the two represents the shoulder axis of rotation (approximate midline of the upper arm). The shoulder joint centre (SJC) is then calculated as the centre of these three markers or from where a vertical line dropped from the acromion intersects the line between the anterior and posterior markers.

The position of the calculated SJC is then recorded in a static trial relative to the coordinate system of the triad located on the upper arm. During a bowling trial the SJC can then be reconstructed relative to the position of the upper arm triad during every frame. Optimisation or helical axis techniques may be used to calculate the shoulder centre, which may modify the markers used about this joint.

#### **Elbow Joint**

The elbow joint centre may be calculated using "epicondyle pointer trials" with the elbow flexed to 90°. The position of the epicondyles should be reported with reference to a triad of markers placed on the upper arm. The elbow joint centre is then calculated as the mid point between these two reconstructed epicondyle virtual markers. This means that the no joint markers are required during bowling trials to reduce errors associated with skin movement. The cameras only need to track the upper arm triad during the bowling action to know where the elbow and shoulder joint centres are. For a background reading in this area refer to Lloyd et al., (Journal of Sports Sciences, 2000, v12). Helical axis determination may also be applied at the elbow joint.

#### **Wrist Joint**

The wrist joint centre may be calculated using "pointer trials" or by placing markers on the styloid processes at the wrist during a static trial. The position of the styloid processes should be calculated as reference points (i.e. three-dimensional co-ordinates) to a triad of markers placed on the forearm. This triad needs to be placed relatively close to the wrist joint centre to avoid excessive skin movement during pronation / supination. The markers on the styloid processes can then be removed prior to bowling data collection. The wrist joint centre is then calculated as the mid point between the styloid process markers or landmarks from the pointer trials.