FIELD VERSUS LABORATORY TESTING IN SPORTS BIOMECHANICS: SYSTEM AND MODELLING ERRORS

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The sport biomechanist is often challenged to 'test performance' during competition and not in the laboratory environment. While ecological validity of data must always be of concern, measurement error (both system, and modelling) and the characteristics of equipment used (manual or automatic?), often mean that data are collected under 'simulated match' conditions. This paper will review the vexing question of laboratory versus field testing from a biomechanical perspective. Current data suggest that for movements involving out of plane rotations, laboratory testing with an opto-reflective system (cluster based model), provides a more accurate measure of elbow angle when compared with the same angle collected with a video-based system (vector model) during a simulated cricket bowling task.

KEY WORDS: measurement error, data validity, motion analysis

INTRODUCTION: The influence of technology has certainly flowed to sport, where technique modification and player movement, based on technology are commonplace. High performance athletes, coaches and governing bodies demand that results are accurately and repeatably obtained within the same testing session and between similar testing environments (field or laboratory). For this reason laboratory testing is typically chosen for biomechanical testing due to the tighter control the tester has over the external environment and therefore the reduced likelihood of 'error' in the data collection process. However, results must also be valid, that is, they must accurately reflect what happens under match conditions and for this reason biomechanists are encouraged to test in match and field based situations. The question of field versus match testing is certainly a vexing issue. System and modelling errors both must be considered, together with the influence of the laboratory testing environment relating to the validity of the collected data.

Research investigating analysis errors attributed to inherent system structure has primarily focussed on video-based and passive opto-reflective systems**.** Ehara et al. (1995) reported that in the calculation of a fixed length segment (0.9 m), percentage error increased from 0.3 to 0.6% when passive reflective systems were compared with video-based systems. In a similar manner Richards (1999) in predicting a 0.5 m distance, reported that the root mean square (RMS) error increased from 0.1 to 0.26 cm for the above comparison. Further the maximum error reduced from 0.96 to 0.32 cm for video-based systems and passive reflective systems respectively. Richards (1999) further reported that RMS error reduced from 2.9 to 2.5° when angular displacement for a revolving rod was measured using video-based versus passive opto-reflective systems respectively. However, the mean RMS error was as low as 1.6° for two of the passive reflective systems. It should be stated that no consideration in the above studies was given to the mathematical model used in data reconstruction. In addition, the comparisons in both studies involved simple comparisons that are essentially basic kinematic measures of linear and angular displacement.

Manually digitising markers is a key characteristic of video-based systems and variability in joint angles of 0.4° of those produced by auto-tracking were recorded when marker and no-marker conditions were compared during treadmill running (Bartlett et al., 2006).Reliable estimation of movement variability was possible when digitising markers by experienced operators. However, a no-marker condition requiring manual visual digitising of relevant landmarks, did not allow reliable estimation of movement variability. Bartlett et al. (2006) reported that movement variability, an important consideration for coaching, could not be assessed objectively in the no-marker condition.

While the error contribution of the analysis system employed is an important consideration in determining either a laboratory versus a field testing approach, errors in the application of the mathematical model employed in the calculation of kinematic variables must also be considered. System and modeling error contributions to data can be partitioned to their respective source. First, the error attributed to the motion analysis system used to obtain raw data (video v infra-red opto-reflective) and secondly, the error attributed to the mathematical model applied to the raw 3D trajectories for the purpose of determining kinematic and kinetic data.

Traditionally, video based models required manual digitising of multiple landmarks from multiple cameras. To minimise the time burden associated with this process early researchers utlised models that allowed for the calculation of kinematic and kinetic data via a minimum number of markers. The resulting "joint centre" approach, whereby the approximated joint centres were manually digitised in all camera views, limited the modelling methods that researchers could employ to relatively simple vector based approaches.

The advent of opto-reflective auto-tracking systems now allows researchers to capture an almost unlimited number of markers, such that a minimum of three markers can easily be positioned to define the true 3D position and orientation of a segment (Cappozzo et al., 1995; 2005). Marker clusters, where markers are attached to semi-rigid plates and arbitrarily affixed to the skin of the segment of interest, may be used to define segment based technical (local) coordinate systems (TCS), whereby the position of relevant anatomical landmarks can be reconstructed in any frame where the TCS is present (Cappozzo et al., 1996). This approach has been shown to reduce errors associated with skin movement artefact in 3D data (Manal et al., 2002) and is the modelling method currently endorsed by the International Cricket Council's bowling review group with regard to the biomechanical testing of cricket bowling.

The aim of this paper is to present preliminary data with respect to system and modelling errors associated with elbow joint flexion/extension in the field versus laboratory debate.

METHODS: A custom designed mechanical arm (Figure 1), representing the human upper limb, was used for all testing. The arm was constructed with one degree of freedom (DOF) at the "shoulder" (allowing flexion-extension in the sagittal plane) and two DOF at the "elbow" (flexion/extension and abduction), which allowed elbow angles to be manually set in the two planes. Two conditions (0° flexion/0° abduction and 20° flexion/20° abduction) are reported in this paper.

Data were collected across two motion conditions. Firstly, the arm was rotated in a manner that resembled shoulder circumduction (planar) by a servo-motor at a speed related to cricket bowling. The second condition involved circumduction and manually rotating the arm in an attempt to simulate upper arm internal/external rotation (IR/ER) during the bowling action. Trials were collected simultaneously using an opto-reflective and a video based system in a laboratory setting. The two elbow settings were also replicated in a field setting using the video-based system. The shirt / no shirt condition was evaluated in the field to assess the effect of wrist, elbow and shoulder joint centre occlusion on manual digitising accuracy.

A Vicon 612 motion analysis system (12 MX3 cameras; ViconPeak**,** Oxford Metrics, UK) operating at 250 Hz was used to record opto-reflective marker clusters placed on the arm segments. These 3 marker clusters were used to define the segment TCSs and associated joint centres. All 16 retro-reflective marker trajectories were

Figure 1: Mechanical arm

automatically reconstructed in the Vicon software and used in the calculation of a 3D elbow joint angle (flexion/extension, abduction/adduction and pronation/supination) using a customised UWA model.
The ViconPeak Motus system (ViconPeak, Oxford Metrics, UK), was used in both laboratory and field environments and employed three NAC cameras sampling at 200 Hz. Manual digitising of the shoulder, elbow and wrist joint centres from all camera views, in the laboratory and the field conditions was performed using ViconPeak Motus software. This facilitated the calculation of a vector based elbow angle. The vector angle was also projected onto the sagittal plane in an attempt to separate out the flexion/extension component of the initial 3D vector angle. A similar unit vector 3D modelling approach to that used in the Vicon modelling process could be employed using a video-based approach. However, the intention of the study is to determine the measurement error of a 'no marker condition', which would resemble video data collected under match conditions.
In addition, associated opto-reflective markers were manually digitised in ViconPeak Motus and exported to a c3d file. This allowed for the same markers from the same trial to be applied to the same model (UWA model) in Vicon software such that any differences in the elbow angle output could be solely attributed to digitising error resulting from system type.
All data were digitised from 10 frames prior to upper arm horizontal to the ground until 10 frames following ball release. Data from both motion capture systems were filtered using a recursive digital Butterworth filter with the same cut-off frequency of 6 Hz, as determined from residual analysis. This figure was similar to the level used by Portus et al. (2003) when analysing cricket bowling.

RESULTS: Data are presented first with system comparisons where the same model has been applied (Table 1), then secondly model comparisons using the video-based system (Table 2) and finally comparisons from the field testing using the video-based system and varying marker conditions (shirt, no shirt) (Table 3).

DISCUSSION: The preliminary data, which in general supports the work of Richards (1999) and Ehara et al., (1995) show:

- When an angle of 20° flexion and 20° abduction is re-set five times at the elbow and the Vicon system and UWA model used in the calculation of the flexion angle at the elbow, a RMS of 0.5° was recorded.
- When the same mathematical procedure (model) is used in the calculation of an elbow flexion/extension angle resulting from raw trajectories collected using different motion analysis systems, error increases from a RMS of 0.5° for an opto-reflective to 2.3° for a video-based system. The mean range in the error across all angle conditions and arm rotations was 0.5° for the opto-reflective system and 2.2° for the video-based system.
- Comparisons of different modelling approaches when using the same data collection system (video-based), sees much larger variations in error level in the approach without markers (vector approach). The RMS 2.3° for a video-based system using the UWA modelling approach increases to 7.2° and 3.9° for vector and projected elbow flexion angles respectively. The introduction of shoulder internal/external rotation markedly increases the error range of the vector and projected vector modelling approaches.
- In a field situation without a shirt, when an arm with a 20° 'carry angle' at the elbow is rotated about its long axis during sagittal plane shoulder circumduction, mean RMS error for the two vector modelling approaches increased from 4.5° for planar rotation to 8.4° in the IR/ER condition.
- When digitising a relatively simple angle such as the elbow during bowling, the wearing of a shirt only marginally increases the RMS error when compared with the no shirt condition, irrespective of vector (6.6° to 7.8°) or projected angle comparisons (3.8.° to 4.1°). A maximum RMS of 16.2° was recorded using the projected vector approach in the IR/ER condition.

Table 1: System error comparisons using UWA Model

	SYSTEM			
	Opto-reflective		**Video-based**	
PLANAR SJ MOTION	RMS	RANGE	RMS	RANGE
0° Flexion / 0° Abduction	0.4	0.5	1.7	2.6
20° Flexion/ 20° Abduction	0.5	0.7	2.6	3.3
PLANAR & IR/ER SJ MOTION				
0° Flexion / 0° Abduction	0.4	0.4	0.6	1.0
20° Flexion/ 20° Abduction	0.5	0.4	4.4	2.0

Table 2: Model comparisons

	VIDEO BASED SYSTEM					
	MODEL					
	UWA		*Vector*		*Projected Vector*	
PLANAR SJ MOTION	RMS	RANGE	RMS	RANGE	RMS	RANGE
0° Flexion / 0° Abduction	1.5	2.6	3.9	2.0	0.6	1.1
20° Flexion/ 20° Abduction	2.6	3.3	12.2	2.3	3.2	1.9
PLANAR & IR/ER SJ MOTION						
0° Flexion / 0° Abduction	0.6	1.0	2.4	3.3	1.4	3.5
20° Flexion/ 20° Abduction	4.4	2.0	10.3	1.9	10.4	17.7

Table 3: Shirt/ No Shirt comparisons in the field

		VIDEO BASED SYSTEM			
		MODEL			
		Vector		*Projected Vector*	
PLANAR SJ MOTION		RMS	RANGE	RMS	RANGE
0° Flexion / 0° Abduction	**No Shirt**	4.0	*0.9*	0.9	*1.5*
20° Flexion/ 20° Abduction		6.6	*2.9*	2.4	2.7
PLANAR & IR/ER SJ MOTION					
0° Flexion / 0° Abduction		8.3	*14.0*	2.9	*3.0*
20° Flexion/ 20° Abduction		7.5	*6.6*	*9.2*	*14.6*
PLANAR SJ MOTION					
0° Flexion / 0° Abduction	**Shirt**	4.6	5.9	1.0	2.5
20° Flexion/ 20° Abduction		9.4	3.8	3.8	5.5
PLANAR & IR/ER SJ MOTION					
0° Flexion / 0° Abduction		6.8	9.2	3.9	6.8
20° Flexion/ 20° Abduction		10.5	17.4	7.8	16.2

CONCLUSION: In cricket, bowlers typically record an elbow extension range of approximately 10° at the elite level irrespective of delivery type. With a tolerance level of 15° it is obvious that the allowable margin for error in testing is relatively small – certainly under 5°. It is therefore clear that testing should be conducted in the laboratory using a cluster based modelling approach with at least three markers per segment. If a video-based system is used then it should be done so in combination with markers that allows some form of cluster based 3D modelling procedure to be implemented. While testing under match conditions may be extremely helpful for qualitative analysis of performance, results from such an analysis will contain large errors, particularly if there is long axis rotation in the movement being analysed.

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