ISSN 1750-9823 (print)
International Journal of Sports Science and Engineering
Vol. 02 (2008) No. 04, pp. 211-215

A Preliminary Forward Solution Model of Cricket Bowling

René E.D. Ferdinands [1], Uwe Kersting [2] and R. N. Marshall [3]

[1] Faculty of Health Sciences, University of Sydney, Australia

[2] Center for Sensory-Motor Interaction, Aalborg University, Denmark

[3] Health and Sport Science, Eastern Institute of Technology, Hawkes Bay, New Zealand

(*Received October02, 2008, accepted November 25, 2008*)

Abstract. In order to produce high ball release speeds, fast bowlers in cricket require high run-up speeds, generate large ground reaction forces, and produce high joint torques. Extensive magnitudes of external loading in combination with kinematic factors such as counter-rotation experienced during fast bowling have been associated with a high incidence of lower lumbar injury. A full mechanical analysis of the technique is lacking such that attempts to modify techniques remain on a trial and error basis. The purpose of this study was to develop a forward solution model to predict the causal factors associated with counter-rotation of fast bowlers. It was shown that a reduction of the shoulder-hip torque differential lead to a minimisation of counter-rotation. This approach potentially gives the cricket coach a scientific means of modifying the technique of high-risk action bowlers to reduce their susceptibility to lower lumbar injury.

Keywords: Forward solution, cricket, bowling, back injury, mixed action

1. Introduction

The objective of fast bowling in cricket is to deliver the ball with a straight arm so that it reaches the batter at high speed after having first bounced once off the ground. The greater the ball speed, the less time the batter has to respond. However, fast bowlers require high run-up speeds, generate large ground reaction forces, and produce high joint torques [1]. With the loading placed on the body, it is not surprising that fast bowlers sustain a variety of serious injuries to the lower lumbar spine. Spinal loading causes stresses and strains on the vertebral structures such as the pars interarticularis, and may eventually lead to fracture [2]. Researchers have investigated the relationship between bowling technique and lumbar spine injury and have found that the amount of counter rotation (rotation of the upper trunk away from the direction of ball delivery in a right-hand bowler) in the transverse plane from back foot to front foot contact is associated with a higher incidence of lumbar injury [3,4].

When the maximum amount of counter rotation is in excess of 30°, fast bowlers are at a higher risk of sustaining lower lumbar injury and this bowling technique is known as a mixed action [4]. In light of this research, coaches suggest technical interventions to decrease the amount of counter rotation in mixed action bowlers [5]. However, no research has yet investigated the causal mechanisms of counter rotation. Hence, the potential efficacy of prescribed technical interventions to reduce counter-rotation is questionable.

Although inverse dynamics methods calculate the net joint torques which represent the sum of muscle actuation that drives the segmental motion in a rigid link segment representation of the human body, the cause and effect relationship between kinetics and kinematics is still difficult to determine [6]. The dynamic equations of motion for even a multiple rigid body system are highly non-linear and very tightly coupled [7]. This leads to a complex pattern of interdependent power flows throughout the system so that the motion of one segment may be caused by the actuation of another segment or even combination of segments far removed from its location in the kinematics chain. Hence, examining the kinetics output to determine the cause of counter-rotation in bowling may not be productive.

A more direct method is to use a forward solution approach in which only the externally applied forces and joint torques are used as input to drive the model [7]. By specifying such inputs into a forward solution

[1] Corresponding author. Tel.: +61-2-93519776; fax: +61-2-93511204
E-mail address: e.ferdinands@usyd.edu.au

model of bowling the kinematics of each segment in each time point during the bowling action are calculated. Though the constraints of forward solution models are considerable when compared to the inverse solutions, such an approach is potentially a powerful diagnostic tool to investigate the causal relations between segmental motions by systematically varying actuator actions.

The purpose of this study was to develop a preliminary forward solution model to alter the effect of counter-rotation movement in fast bowling technique. This approach explores the causal relations between the generation of counter-rotation motion and other kinematic properties of the bowling technique. We hypothesise that changes in the shoulder-hip torque differential input in a forward solution simulation of bowling will affect shoulder-hip alignment and shoulder rotation [8]. Ultimately, this approach could be used to investigate means of modifying the techniques of mixed action bowlers to reduce counter-rotation, subsequently reducing their susceptibility to lower lumbar injury. Simultaneously, interactions with other segment actions can be monitored.

2. Data Collection

A mixed action, right-handed fast bowler with front-on shoulder alignment was selected as a subject for this study. Eight Falcon Motion Analysis High Resolution cameras acquiring data at 240 Hz, were placed around the subject so that the fields of view were sufficient to capture the performance area of the trials. Forty-eight reflective markers were placed on the body so that the centre of joint rotation could be calculated for all the major segments: head and neck (as one segment), thorax, lower trunk, thighs, shanks, feet, upper arms, forearms, and hands. An EVa 3D motion analysis system (Motion Analysis Corp.) was used to track and analyse the movement trajectory of these markers when the subject performed a trial.

The complete set of joint centres and markers were used to derive the local segment coordinate systems of a fifteen-segment rigid body model. Essentially, the process for each local coordinate system involved defining (i) the *y*-axis vector as coincident with the long axis vector of a segment, (ii) the *xy*-plane vector for a marker on the segment that was non-collinear with the *y*-axis, (iii) the z-axis vector by calculating the cross product between the long axis and xy-plane vectors and (iv) the *x*-axis vector by calculating the cross product between the z-axis and y-axis vectors [9]. This process was used to produce a system of fifteen local coordinate systems with three-dimensional orthogonal axes. The motion of the human body model in three-dimensional space was described using the *xyz*-coordinates of the origin of the local coordinate systems and the *zyx*-Euler angle sequence of local coordinate systems with respect to the global laboratory coordinate system. A full set of three-dimensional linear and angular kinematics data were calculated.

The subject was requested to bowl ten balls at maximum speed on an artificial surface at a target (the stumps) 20 m away, while making back and front foot contact with Bertec force plates (sampled at 960 Hz) during the delivery stride. The six fastest balls that were delivered to an area the width of a cricket pitch and within a 0 - 5 m range from the target were selected for analysis. A recursive Butterworth fourth-order low-pass filter was used to smooth the kinematic data (Winter, 2005). The cut-off frequencies were estimated by using the Fast Fourier Transform analysis functions in Mathematica (Version 5.0, Wolfram Research Ltd.). Quintic splines were used to interpolate and convert the smooth kinematics data into functions of time. These data were then in a suitable form for the inverse solution calculations of resultant joint torques and forces, necessary for the direct dynamics simulation.

3. The Rigid Body Bowling Model

3.1. Inverse Dynamics Model

An three-dimensional (3D) inverse dynamics model of the human body was developed using the Mechanical Systems Pack, a set of Mathematica (V 5.0, Wolfram Research Ltd.) packages designed to assist in the analysis and design of spatial rigid body mechanisms [10]. This pack is written entirely in the Mathematica programming language and is completely portable and platform independent. Mathematica integrates a numeric and symbolic computational engine, graphics system, and programming language to perform various mathematical computations. Using the library of 3D geometric constraints in the Mechanical Systems Pack, complex mechanical relationships and algebraic constraints were applied to model the human body as a system of rigid body segments. Object-oriented, model-building commands assemble constraints to connect rigid bodies into a complete mechanism that were solved for dynamic forces when segment inertia properties were defined. Dynamics equations of motion were generated and solved using a Newtonian-Lagrange Multiplier iterative method. We modelled 15 body segments with inertial properties (mass, mass centroid, and moment of inertia), and defined the local reference systems for each body. The segments were linked together using Newtonian constraint equations, and solved iteratively using the Newton-Raphson method. A spherical constraint function was used to constrain two points as coincident in three-dimensional space, constraining three degrees of freedom. Driving constraints were used to specify the angular orientation of the body segments in terms of Euler angles.

External loads on the segments, such as gravitational forces, ground reaction forces, and ground reaction moments were generated by the Mechanical Systems Pack as functions of Lagrange multipliers. In addition, the ground reaction forces were defined as load switching functions explicitly dependent on time. The initial guesses of the segment configurations, which were needed for the iterative solution, were provided from the initial conditions of the kinematic data. Finally, the Lagrange multiplier equations of motion were solved iteratively to calculate the external joint torques and forces on the body, which could be calculated throughout the entire bowling action.

3.2. General Forward Solution Procedure

In a forward or direct dynamics solution, the equations of motion are numerically integrated for a specified time with respect to a set of initial conditions. An Adam-Bashforth numerical integration method was implemented in the software, which is of variable order, variable step size, and adaptive. The kinetic data from the inverse solution were used as time-dependent input variables in the forward solution model to confirm that the resulting kinematic data of the simulated bowling action matched that of the bowling action during the respective trial. This forward solution model was then taken as the base model to test the effects of changes in joint torque inputs on the simulations. We ran two simulations: (i) the effect of increasing shoulder counter-rotation from back foot contact to front foot contact, and (ii) the effect of decreasing shoulder-hip alignment at back foot contact on the kinematics of the bowling action.

3.3. Increasing Shoulder Counter-Rotation

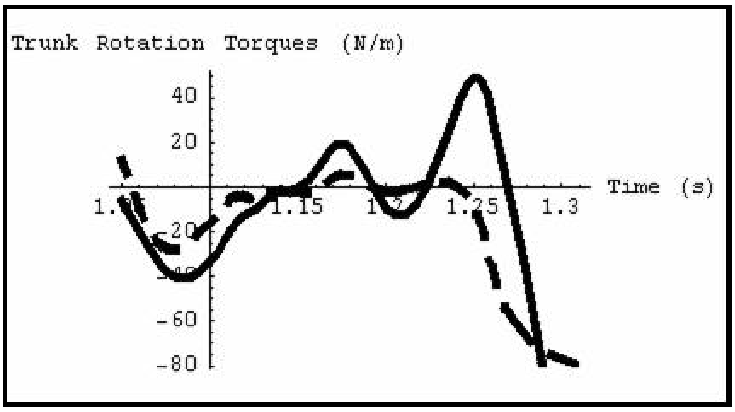

Figure 1: Shoulder-hip torque differential inputs. Upper trunk rotation torque (solid) and hip rotation torque (dashed). Positive values indicate anticlockwise torques about their respective long axes.

The initial conditions of the forward solution model were specified from just prior to back foot contact. The process of simulating a modified bowling action was based on increasing the difference between the shoulder and hip rotation torques from back foot to front foot contact to increase counter-rotation and analyse the kinematics at front foot contact (Figure 1). The ratio of shoulder to hip rotation torques (γ) was increased incrementally in steps of 0.01 by linearly increasing the clockwise upper trunk torque about the longitudinal axis and decreasing the corresponding torque of the lower trunk by an equal amount during the early part of the back foot contact phase (1.05s to 1.15s) prior to front foot contact. All other joint torque inputs were the same as calculated in the inverse solution model, and were not altered.

3.4. Decreasing Shoulder-Hip Alignment Differences

The initial conditions of the forward solution model were specified during the flight phase prior to back foot contact. The process of simulating a modified bowling action was based on decreasing the difference between the shoulder and hip rotation torques from during the flight phase so that the shoulders and hips would be more aligned at front foot contact (Figure 1). The ratio of shoulder to hip rotation torques (γ) was decreased incrementally in steps of 1% by linearly decreasing the upper trunk torque about the longitudinal axis until the angle between the shoulders and hips was minimised. All other joint torque inputs were the same as calculated in the inverse solution model, and were not altered.

4. Simulation of the Model

4.1. Counter-rotation

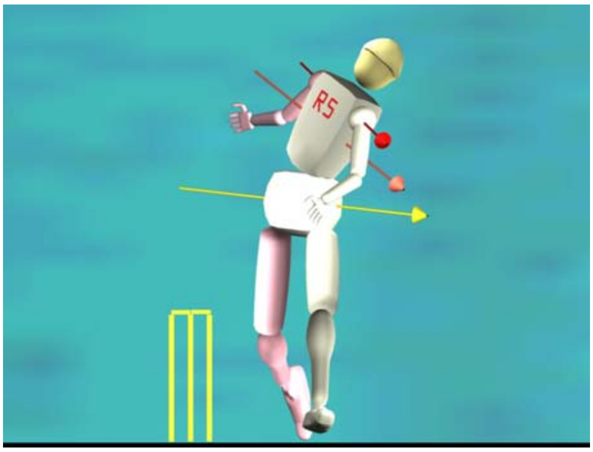

Figure 2: Computer animation of bowlers with counter-rotation have increased lateral lean or bending at front foot contact.

The simulation of the bowler under modified torque inputs to increase the shoulder-hip torque differential (γ = 1.3) was found to increase the amount of lateral lean (15.3º), hyperextension (10.2º), and shoulder counter-rotation (8.0º) at front foot contact. Increasing γ from 1 to 1.3 increased the severity of those factors that constitute a mixed action (Figure 2). However, as γ was increased more than 1.3 the solution became unstable. At these values of lateral bending of the trunk segments increased in excess of 45° and the movements of other segments such as the arms and legs did not resemble a coherent motion. The forward solution simulation suggests that an increased torquing between the shoulders and hips during early back foot contact phase can promote shoulder-counter-rotation in bowling. The simulation also suggests that counter-rotation is coupled with lateral bending. This is consistent with research showing that mixed action bowlers have more lateral flexion and hyperextension of the lumbar spine during the delivery stride [1].

4.2. Shoulder-hip alignment

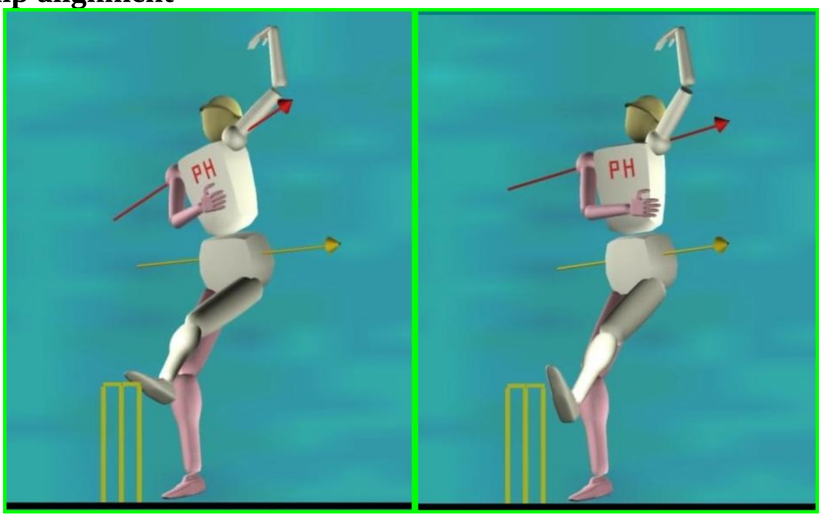

Figure 3: The shoulder-hip alignment was reduced by reducing the shoulder torque.

When γ was decreased to 0.85 the shoulder hip separation angle reached a minimum of 5.5° at back foot contact. Further reduction of γ did not reduce the shoulder hip separation angle without severely distorting the bowling action. We found that by incrementally increasing the lateral bending torque to elevate the shoulders the solution could be stabilised and the shoulder-hip separation angle reduced to 0.0°. We chose to alter the lateral bending torque because progressive simulations showed that there was a functional relationship between γ, lateral bending of the trunk and shoulder-hip separation angle. As the lateral bending torque was increased there were two other observable changes in the simulated action: the front thigh became more adducted, and the front arm became more abducted and flexed. Both these kinematic characteristics have been observed in front-on bowlers.

5. Limitations

This is primarily a methodological paper to show the potential of a forward solution model in cricket bowling as a diagnostic tool to investigate mixed action techniques. This is a preliminary approach and there were some notable methodological limitations. The bowler was modelled as a rigid body model with inertial properties defined from standardised regression equations. This is particularly problematic for the trunk segments that may have significant tissue movement during rapid motions. Such errors in modelling would be multiplied through the link segment chain. Also, there was no formalised optimisation algorithm to solve a minimisation problem. Instead, the power of the objective function had to be manually set by the user. The difficulty of the forward dynamics problem lies in the fact that there are many possible activation torques for a given movement. Hence, further research is needed to develop optimisation algorithms that will lead to the constrained minimization of selected objective functions.

6. Conclusions

We developed a forward solution model of bowling to predict body segment trajectories in a bowling action resulting from any pattern of joint torques. Though there was no formalised optimisation approach, we were still able to alter torque inputs to test what their effect was on the motion in a functional sense. We found that changes in the values of the shoulder and hip torques could alter shoulder-hip separation angle, lateral bending of the trunk, front leg adduction and shoulder counter-rotation. This indicates that coaches should consider the effects of these dynamic segment interactions before implementing techniques to reduce counter-rotation in bowling. One limitation with forward solutions models is that they are complex and an optimal solution may not always be found. However, this is offset by the fact that forward solutions provide a rich potential of diagnostic evaluation of performance and injury indicators, and should be pursued in many aspects of sports biomechanics.

7. Acknowledgements

We thank Warren Frost (Sports Science Sports Science and Medical Coordinator, New Zealand Cricket) for supporting New Zealand Cricket's funding of the post-doctoral component of this study.

8. References

[1] Ferdinands, R.E.D. Three-dimensional biomechanical analysis of fast bowling in cricket. Unpublished PhD Thesis, University of Waikato, 2004.

[2] Yingling, V.R. and McGill, M.S. *Anterior shear of spinal motion segments kinematics, kinetics, and resultant injuries observed in a porcine model Spine*. 2000, **24** (18): 1882–1889.

[3] Bartlett, R.M. The biomechanics of fast bowling in men's cricket: A Review. *Journal of Sports Sciences.* 1996, **14** : 403-424.

[4] Elliott, B. C. Back injuries and the fast bowler in cricket. *Journal of Sports Sciences*. 2000,**18** (12): 983-991.

[5] Elliott, B.C. and Khanghure, B. Disk degeneration and fast bowling in cricket: an intervention study. *Medicine & Science In Sports & Exercise.* 2000: 1714-1718.

[6] Putnam, C.A. Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *Journal of Biomechanics.* 1993, **26**(1): 125-135.

[7] Winter, D.A. *Biomechanics and Motor Control of Human Movement (3rd Ed).* New Jersey: John Wiley & Sons, Inc., 2005

[8] Burnett,A.F., Barrett,C.J., Marshall, R.N., Elliott, B.C. and Day, R.E. Three-dimensional measurement of lumbar spine kinematics for fast bowlers in cricket. *Clinical Biomechanics.* 1998, 13: 547-583.

[9] Grood, E.S. and Suntay, W.J. A Joint Coordinate System for the Clinical Description of Three-dimensional Motions: Application to the Knee. *Transactions of the ASME*. 1983, **135**: 136 - 144,

[10] Dynamic Modelling. *Mathematica Mechanical Systems User's Guide.* Wolfram Research, Inc., Champaign, Illinois, 1995.