A Fifteen-Segment 3D Rigid Body Model of Bowling in Cricket

R.E.D. Ferdinands[1], K.A. Broughan[2], H. Round[1], R.N. Marshall[3]
[1]Department of Physics & Electronic Engineering, University of Waikato, New Zealand
[2]Department of Mathematics, University of Waikato, New Zealand
[3]Department of Sport & Exercise Science, University of Auckland, New Zealand

Introduction

The function of bowling in cricket is to deliver the ball to the batter such that the ball first bounces once off the ground. The laws of cricket specify that any straightening of the bowling arm must occur well before the time of ball release. A computer simulation of the bowling action is shown below (Fig. 1).

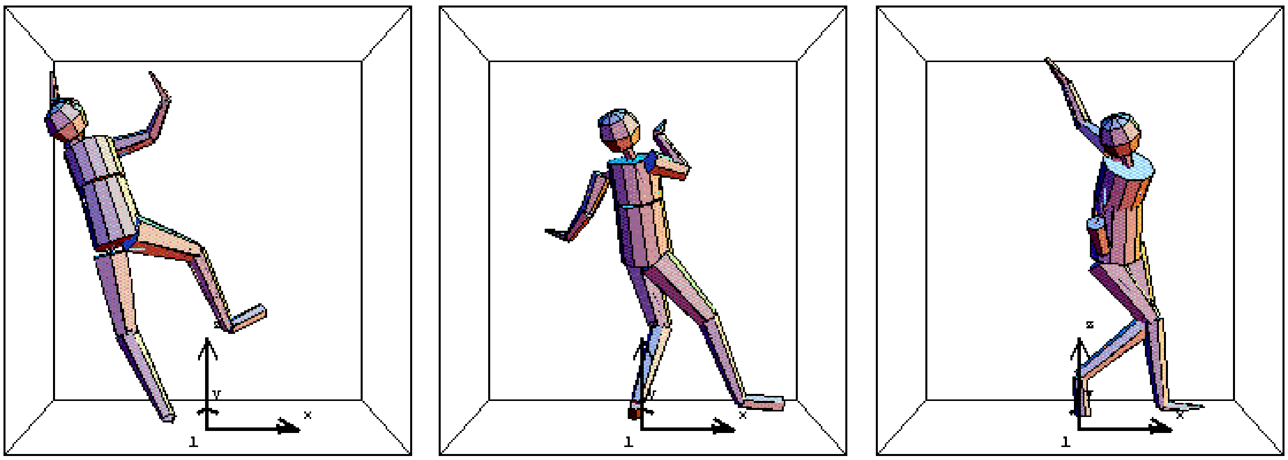

Figure 1: A computer simulation in *Mathematica* of the bowling action used by the subject in this study. A good technique allows the bowler to deliver a ball with speed at a chosen point on the pitch while maintaining a straight bowling arm. Note the sense of the torques and forces is defined with respect to the global reference XYZ system shown. The plane of progression is the XZ plane.

Research in this area has been largely confined to the analysis of kinematics and force plate data. Although a 2-dimensional (2D) two-segment model has been previously used to simulate the trajectory of the bowling arm, there are no published models representing the dynamics of the full human body during the motion of bowling. We present a biomechanical analysis of bowling using the results obtained from the dynamical simulation of a 3D rigid body model of the human body.

Methods

Data Capture: An international spin bowler was the subject for this study. Eight Falcon Motion Analysis High-Resolution cameras, set at a frame rate of 240 Hz, were placed around the subject so that the field of view was sufficient to capture the performance area of the trials. Forty-eight retroflective markers were strategically placed on the subject. We used an EVa 3D motion analysis system (by Motion Analysis Corp.) to track and analyze the movement trajectory of these markers when the subject performed a trial. By using EVa's Virtual Marker facility, we could define and calculate the center of joint rotation for all the major body segments (Fig. 2).
The subject performed two trials. In the first trial, the subject had to bowl six balls at the stumps 20 m away, while making sure that the front foot made contact with a Bertec Force Plate (960 Hz) during delivery stride. In the second trial, the subject had to perform the same as before, but now make back foot contact with the force plate. The force plate readings of the back foot were then averaged, and combined with the force plate readings from the first trial. Then the six balls in the first trial were chosen for kinetic analysis. We used a fourth-order recursive Butterworth filter (cut-off frequency 4-7Hz) to smooth the data.

Inverse Solution Model: An inverse 3D dynamic model of the human body was developed using the *Mechanical Systems Pack*, a set of *Mathematica* (Wolfram Research, Inc., V. 3.0) packages designed to assist in the analysis and design of spatial rigid body mechanisms (Dynamic Modeling, 1995).

The *Mechanical Systems Pack* generated the equations of motion using a Newtonian-Lagrange Multiplier method. We created 15 segments with the *SetBodies* function, which set the inertia properties (mass, centroid, and moment of inertia), and the local reference systems for each body (Fig. 2). The segments were linked together using the *SetConstraints* function, which generated the Newtonian constraint equations, and solved them iteratively with a Newton-Raphson method. The input for the angular kinematic data was specified within the *SetConstraints* function, and the positional data of the shoulder and hip joints were defined within the *SetBodies* function.

External loads to the segments, such as gravitational forces, ground reaction forces, and ground reaction moments, were set using the SetLoads function, which generated the Lagrange multiplier equations of motion. Then we used SolveMech to calculate the external joint torques and moments.

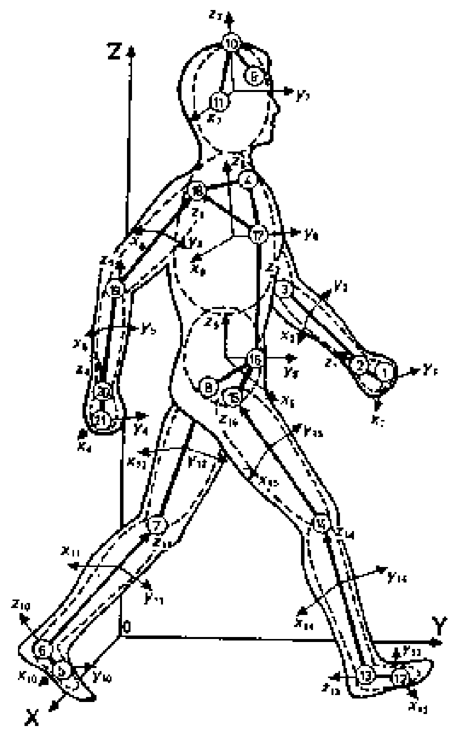

Figure 2: A 15 segment 3D rigid body model of the human body. This model was defined by using the *SetBodies* and *SetConstraints* functions in the *Mechanical Systems Pack*. [From Zatsiorsky, V.M., 1988. *Kinematics of Human Motion*. Human Kinetics, Champaign, Illinois.

Forward Solution Model: To run a forward or direct dynamics solution we used the *SolveFree* function to integrate the equations of motion for a specified time domain, and set of initial conditions. *SolveFree* implements an Adam-Bashforth numerical integration method, which is variable order, variable step size, and adaptive. We ran the forward solution model as a check for the inverse dynamic solutions.

Results and Discussion

We compared the joint torque and force profiles of the subject for the six balls bowled and found that the kinetic characteristics were similar. However, rather than average the torque and force profiles, we selected one typical ball for analysis. Also, to check the validity of the inverse solution, we ran a forward solution, and found that the outputs of this simulation closely matched the data that served as input to inverse solution. Note that all references to torques and forces in the subsequent discussion are defined with respect to the global reference system (Fig. 1).

It is commonly held that the non-bowling arm (right arm in this case), should be accelerated clockwise to propel the trunk and bowling arm forwards (Philpott, 1973). However, the technique of the subject does not show this characteristic. Instead, from the time when the bowling arm is horizontal and extended behind (0.28 s) to the point of ball release (0.40 s), the non-bowling arm is subject to a negative (anticlockwise) torque in the XZ plane (Fig. 4a). In addition, the torques about the Y-axis on both the upper and lower trunks of the subject are mainly negative during this period, retarding the flexion motion of the trunk (Fig. 4b).

Elliott et al. (1986) reported that the bowling arm makes a significant contribution to ball release speed. It is expected therefore that the torque on the bowling arm would be maximal during the period of greatest acceleration (> 0.28 s), which generally occurs after the bowling arm has passed the horizontal behind the body. However, the average torque on the bowling arm about the Y-axis during this period was -50Nm, which acted to decelerate the arm. This seems a surprising result, but it is the force at the shoulder joint acting in the negative X-direction that is responsible for much of the arm's acceleration (Fig. 5a).

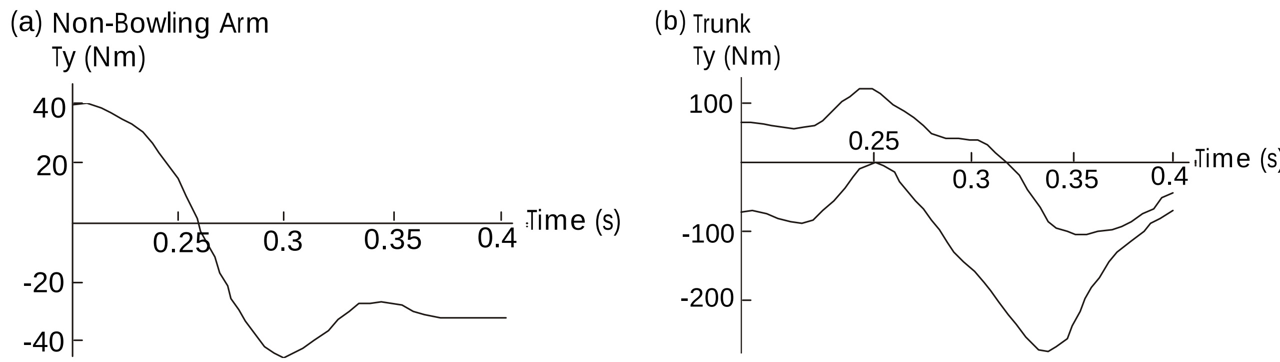

Figure 4: (a) The non-bowling arm torque about the Y-axis is negative for the period when the bowling arm is above the horizontal (> 0.28 s). (b) After the bowling arm has reached the horizontal, the torque about the Y-axis on lower trunk (lower curve) is negative, and the torque on the upper trunk (upper curve) is negative after 0.32 s.

A common technique in spin bowling is to thrust the rear hip forward with the knee bent to accelerate the motion of the bowling arm. However, the torque on the rear leg of the subject acted to decelerate the forward motion of the thigh in the XZ-plane when the bowling arm was accelerating above the horizontal (Fig. 5b). Instead, the driving action of the rear hip occurred earlier during a short period after front foot plant (0.22 s).

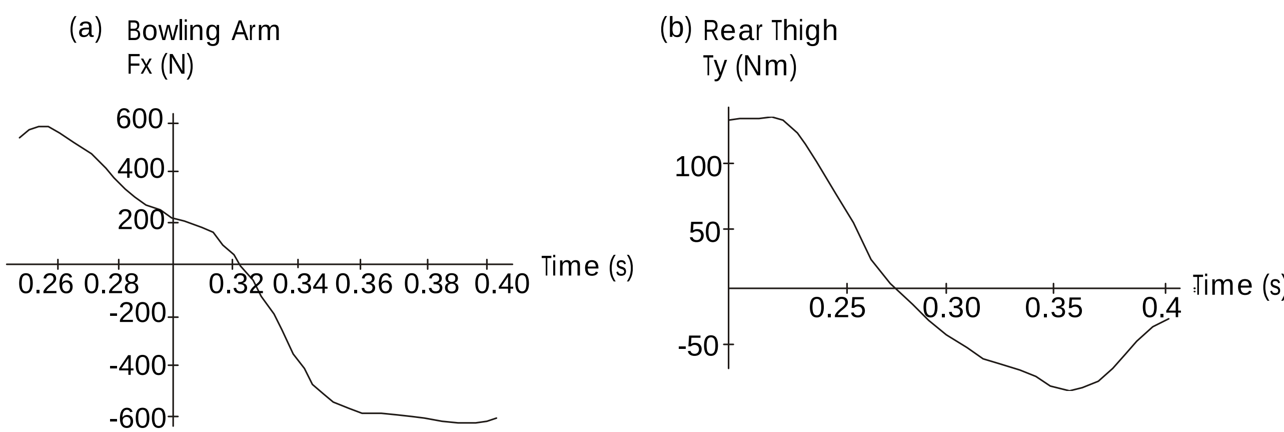

Figure 5: (a) The force acting at the shoulder joint of the bowling arm rapidly decreases and begins to act in the negative X-direction after 0.32 s when the arm is above the horizontal. This serves to increase the angular velocity of the bowling arm. (b) The torque on the rear thigh about the Y-axis is negative when the bowling arm is above the horizontal and accelerating.

This study is the first time that a 3D full body analysis of bowling has been carried out, and from only the small selection of techniques chosen for analysis, we believe it has shown that bowling is a mechanically complex movement. The subject did not conform to certain established technical principles. This is an important result, as the subject is an internationally renowned performer, and the technical principles that govern his action should be taken seriously. Future studies involving a larger sample of subjects have already been planned.

References

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