MODELLING NON-PLANAR PELVIS AND TRUNK ROTATIONS
IN A PLANAR SIMULATION MODEL

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In whole body planar simulation models the bilateral hip and shoulder joint centres are
assumed to be symmetrical. Non-planar rotations of the pelvis and trunk can cause
these joint centres to be asymmetrical. In order to allow asymmetrical hip and shoulder
joint centres in a planar simulation model a massless segment method was used in an
angle driven simulation model of the front foot contact phase of fast bowling. The model
was customised to an elite fast bowler by closely matching three performances and
evaluated. It was concluded that the massless segments method to allow asymmetrical
hip and shoulder joint centres within a planar simulation model was suitable to reproduce
predominately planar movements.

KEY WORDS: cricket, fast bowling, performance, massless segment method

INTRODUCTION: A forward dynamics simulation model for fast bowling is required in order
to investigate the factors which limit fast bowling performance (Ferdinandis et al., 2008;
Worthington et al., 2013b). Attempts to develop a forward dynamics torque driven simulation
model of cricket fast bowling have been restricted due to the difficulties associated with
obtaining realistic joint torque parameters (King and Yeadon, 2015) and the complexity
required to optimise a three-dimensional whole body model (Ferdinandis et al., 2008).
Experimental research has shown that the key characteristics linked to performance occur
during the front foot contact phase of fast bowling (Worthington et al., 2013a). During this
phase the movement is predominately planar although non-planar rotations of the pelvis and
trunk may occur.

Computer simulations of predominately planar movements have previously been modelled
by either assuming planarity (Allen et al., 2012) or using a pseudo-3D solution (Brewin et al.,
2000). In simulation models assuming planarity, the bilateral hip and shoulder joint centres
are assumed to be symmetrical (coincide in the sagittal plane). Non-planar rotations of the
pelvis and torso can cause the hip and shoulder joint centres to become asymmetrical
violating the assumption of planarity and potentially affecting the ability of the simulation
model to accurately reproduce the performance. Asymmetrical hip and shoulder joint centres
have not previously been employed in planar simulation models although extra degrees of
freedom have been used in a high bar simulation to allow the length of the torso to increase
(Begon et al., 2008, Hiley and Yeadon, 2013).

This study will investigate if using asymmetrical hip and shoulder joint centres to incorporate
non-planar rotations of the pelvis and trunk allows a whole body simulation model of fast
bowling to accurately reproduce the performance.

METHODS: A planar sixteen segment angle driven computer simulation model of the front
foot contact phase of fast bowling (Figure 1) was constructed using Autolev⁷ (Kane and
Levinson, 1985). Fourteen rigid segments represented the: head + trunk, two upper arms,
two thighs, two shanks, two two-segment feet, forearm + hand (non-bowling arm), forearm
(bowling arm) and hand (bowling arm) with wobbling masses within the shanks, thighs and
trunk. Two massless segments were also used. One to connect the bilateral hip joint centres
and the other to connect the bilateral shoulder joint centres. These segments had variable
length and orientation (about the trunk + head segment) which allowed the joint centres to
be asymmetrical. The length of the trunk + head segment was also allowed to vary with the
centre of mass position moving accordingly to incorporate the effect of side flexion. Each
foot had three points of contact with the ground at the heel, ball (metatarsophalangeal joint), and toe. A ball was included at the end of the bowling arm hand as a point mass.

![Image of a bowling simulation model](image)

**Figure 1 - Sixteen-segment simulation model with wobbling masses within the shank, thigh and trunk segments, angle drivers at all joints (white circles) and spring-dampers at three points on each foot.**

The simulation model was customised to an elite fast bowler by determining subject-specific segmental inertia parameters (Yeaton, 1990). A common set of viscoelastic parameters representing the attachments of the wobbling masses and the foot-ground interface were determined for three fast bowling performances using an adaptation of the method of Wilson et al. (2006). The simulation was driven using the joint angle time histories, the massless segment orientation-time histories, and the variable segment length-time histories derived from recorded performances of an elite fast bowler. A total of 34 parameters were varied via a simulated annealing algorithm (Kirkpatrick et al., 1983) in order to minimise an objective function representing the difference between the simulation and the recorded performances. The objective function was the average of an RMS score given to each of the three matched bowling performances consisting of the differences between performance and simulation in four components: force, centre of mass velocity, orientation angle and ball release speed. Each difference was weighted equally and one degree was equivalent to 1% difference in other measures (Yeaton & King, 2002). Penalties were employed to limit horizontal slide and vertical compression of the front foot during impact as well as the movement of the wobbling masses. The model was evaluated further using the common set of viscoelastic parameters to simulate a fourth performance.

**RESULTS & DISCUSSION:** The common set of viscoelastic parameters determined by concurrently matching three bowling trials were seen to provide a close overall agreement, 5.8%, with individual performance scores of 6.0%, 5.5% and 5.9% (Table 1). Evaluating the common set of viscoelastic parameters using a further bowling performance also provided a good level of agreement, 5.3% (Table 1; Figure 2).

<table>
<thead>
<tr>
<th>Component</th>
<th>Match 1</th>
<th>Match 2</th>
<th>Match 3</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (%)</td>
<td>11.9</td>
<td>10.7</td>
<td>11.5</td>
<td>10.6</td>
</tr>
<tr>
<td>COM velocity (%)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Trunk orientation (°)</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Ball release speed (%)</td>
<td>1.3</td>
<td>2.2</td>
<td>2.2</td>
<td>0.2</td>
</tr>
<tr>
<td>RMS (%)</td>
<td>6.0</td>
<td>5.5</td>
<td>5.9</td>
<td>5.3</td>
</tr>
</tbody>
</table>
The average score of 0.8% for the kinematic components (COM velocity, trunk orientation and ball velocity) indicates that the simulation model has sufficient complexity to reproduce the kinematics of the front foot contact phase of the fast bowling action. The average score of 11.2% for the kinetic component (force) is considered to be a good agreement when using a pin-joint simulation model to reproduce ground reaction forces due to the problems associated with a lack of compliance throughout the system. Allen et al. (2012) used an angle-driven simulation model of triple jumping to show that pin-joint simulation models were suitable to reproduce ground reaction forces of human movement with a best kinetic score of 15% (adjusted for comparison). Further comparison between the simulated and performance ground reaction forces (Figure 3) confirm that the key features have been maintained and this simulation model is suitable to reproduce the ground reaction forces of the front foot contact phase of the fast bowling action.

Comparing the simulations and recorded performances indicates that allowing the bilateral hip and shoulder joint centres to be asymmetrical using massless segments with variable length and orientation provides enough complexity to accurately model the kinematic and kinetic features of the front foot contact phase of the fast bowling action. The use of massless segments however should be limited to movements in which the non-planar rotations have a minor influence on the overall performance. Failure to do so may result in a simulation model providing insights into the mechanics of a movement. It should also be remembered that planar simulation models cannot be used to investigate the cause and effect relationship of out of plane movements therefore, it is not suitable to use this method.
and then subsequently use the model to investigate the effect of non-planar rotations on performance.

CONCLUSION: This study has identified a method in which the bilateral hip and shoulder joint centres in a planar simulation model can be asymmetrical using massless segments. In the future, this method could be used in predominantly planar movements where non-planar rotations of the pelvis and trunk cause asymmetrical hip and shoulder joint contor with widening the potential of planar simulation models to investigate human movement accurately.

REFERENCES:

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