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 (Ferdinands 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 (Ferdinands 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 Autolev™ (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.

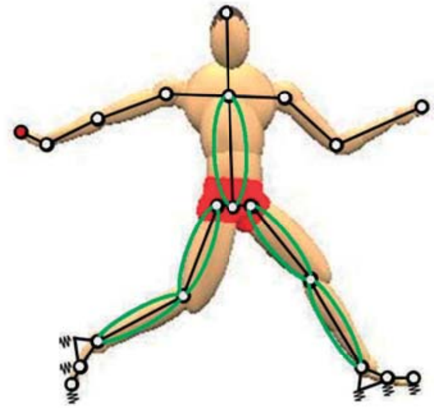

Figure 1 - Sixteen-segment simulation model with wobbling masses within the shank, thigh and trunk segments, angle drivers at all joints (white circles) and spring-dampers at three points on each foot.

The simulation model was customised to an elite fast bowler by determining subject-specific segmental inertia parameters (Yeadon, 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 (Yeadon & 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 1
RMS scores for the three matching and evaluation simulations with component differences

Component	Match 1	Match 2	Match 3	Evaluation
Force (%)	11.9	10.7	11.5	10.6
COM velocity (%)	0.1	0.1	0.1	0.2
Trunk orientation (°)	0.9	0.9	0.8	0.8
Ball release speed (%)	1.3	2.2	2.2	0.2
RMS (%)	6.0	5.5	5.9	5.3

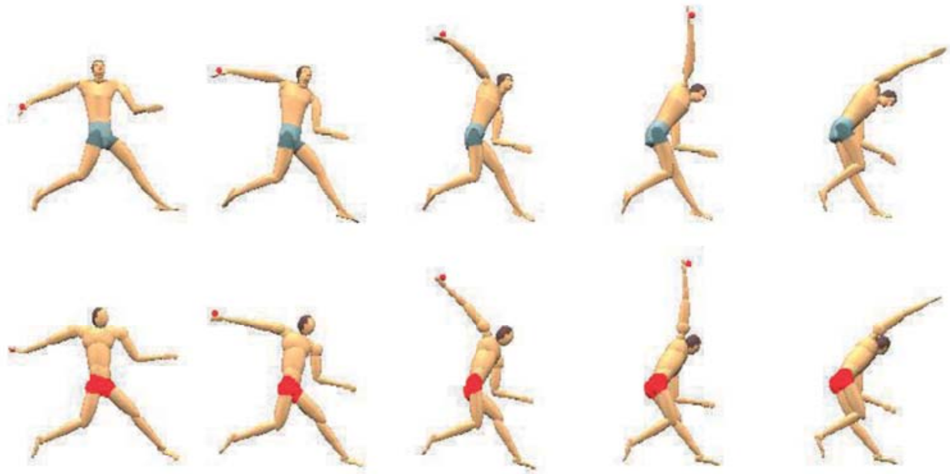

Figure 2 – Comparison of the front foot contact phase of fast bowling: recorded performance (upper) and angle-driven evaluation (lower).

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.

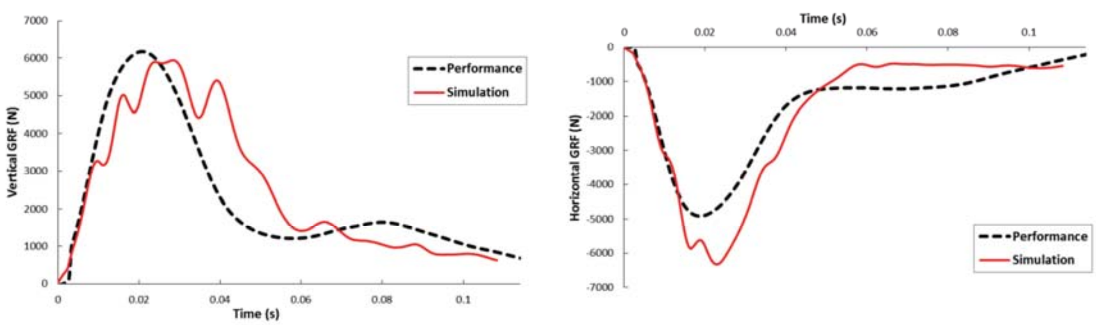

Figure 3 – Comparison of the vertical and horizontal ground reaction forces for a simulation vs. performance.

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 predominately planar movements where non-planar rotations of the pelvis and trunk cause asymmetrical hip and shoulder joint centres widening the potential of planar simulation models to investigate human movement accurately.

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