To what extent can a driven double inverted pendulum model of human gait explain the joint kinematics and kinetics of single support?

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INTRODUCTION

There are two main types of gait modelling: simple link-segment [1, 2] and complex, multiple degrees of freedom, musculoskeletal ones [3, 4].
There seems to be justification for incrementally increasing the complexity of simple models so that the contribution of each subsequent addition can be highlighted.
The mechanics of the inverted pendulum, with regards to biped walking, have been well documented [1, 5, 6] so a slightly more complicated model was designed.

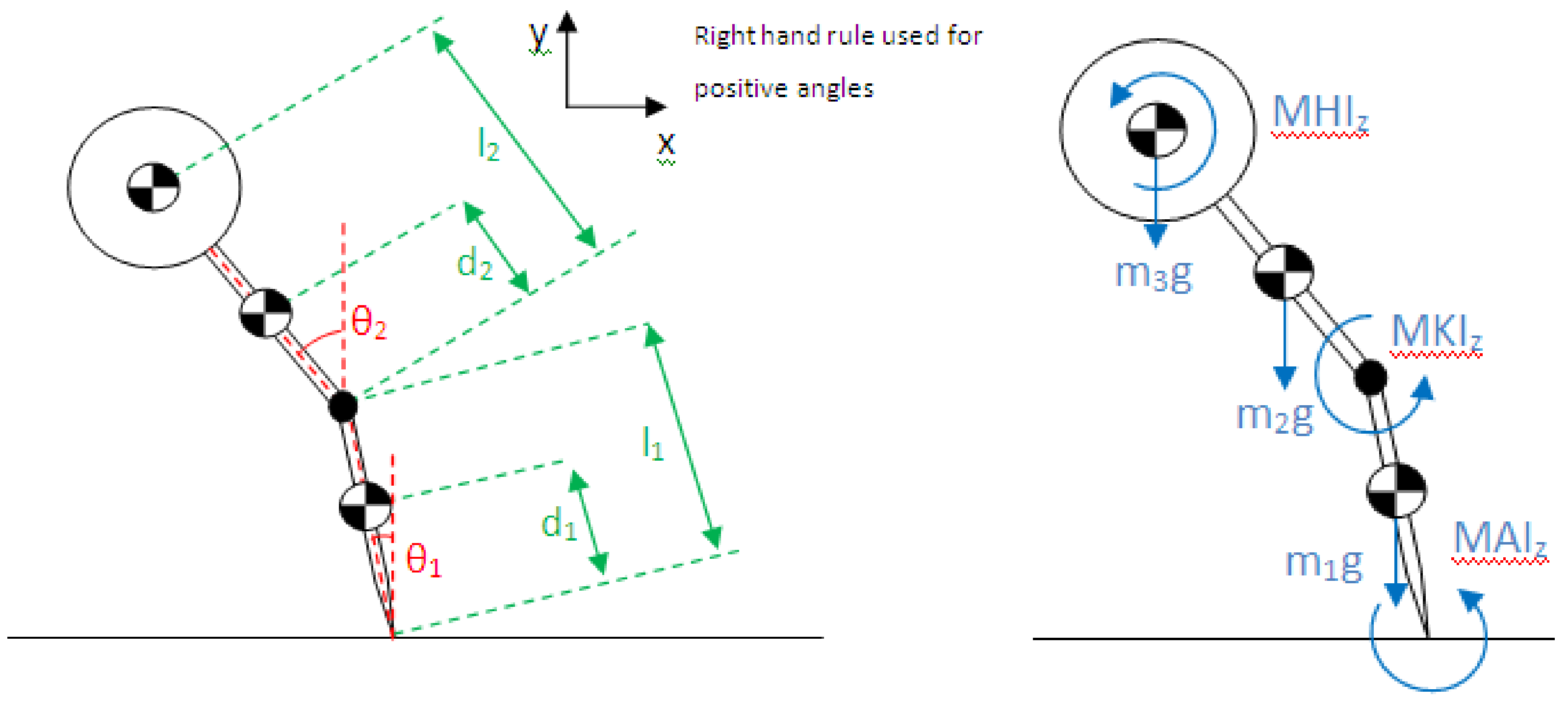

Figure 1: Schematics of the double inverted pendulum model showing kinematic and kinetic properties

METHODS

A hinged knee joint between two rigid beams was used to create and double inverted pendulum model of stance leg. The whole masses of the shank and thigh segments (calculated from the data of Winter [7]) were assumed to act at points on the beams, known distances from the distal ends. The rest of the mass of the body was assumed to act at a point at the proximal end of the thigh segment. Each segment had a given inertia.

Controllable joint moments were applied at the hip, knee and ankle joints. Lagrangian mechanics were used to solve the equations of motion of the model.

Using the Global Optimisation toolbox for MATLAB, an optimisation problem was set up. The variables to be optimised were the coefficients of the cubic equations that defined the applied moments and the initial angles and initial angular velocities of the two segments. Each output was compared to normative reference data at 21 points of the cycle, normalised by standard deviation. The root mean square (RMS) value of these data was then used to determine how closely the simulated curves fitted the practical data. The cost function of the optimisation was equated by summing the RMS values for the parameters to be matched.

RESULTS

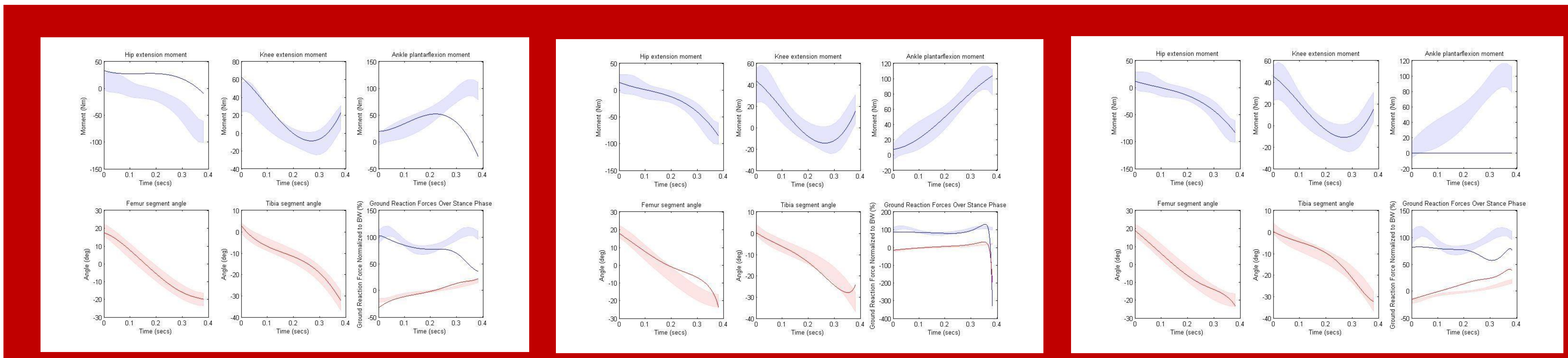

Figure 2: The simulation results (solid lines) compared to empirical findings (shaded areas; one standard deviation either side of the mean). Trial 1 (left) optimised kinematic properties only. Trial 2 (centre) optimised both kinematic and kinetic properties. Trial 3 (right) also optimised both kinematic and kinetic properties but excluded an ankle moment.

DISCUSSION

- Using the optimiser to find a match between kinematic predictions and empirical data produces poor kinetic predictions.

- Using the optimiser to match both kinematic and kinetic properties with their respective empirical counterparts produces the best GRF prediction of the three trials.

- Trial 3 highlighted the importance of the ankle moment in these kinds of simulations.

- The lack of foot segment appears to be the cause of the weak predictions, in all trials, towards the latter stage of single stance.

REFERENCES

1. Pandy, M.G., *Simple and complex models for studying muscle function in walking.* Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 2003. **358**(1437): p. 1501-1509.
2. Duan, X.H., R.H. Allen, and J.Q. Sun, *A stiffness-varying model of human gait.* Medical Engineering & Physics, 1997. **19**(6): p. 518-524.
3. Anderson, F.C. and M.G. Pandy, *Individual muscle contributions to support in normal walking.* Gait & Posture, 2003. **17**(2): p. 159-169.
4. Anderson, F.C. and M.G. Pandy, *Dynamic optimization of human walking.* American Society of Mechanical Engineers, 2001. **123**(5): p. 381-390.
5. Buczek, F.L., et al., *Performance of an inverted pendulum model directly applied to normal human gait.* Clinical Biomechanics, 2006. **21**(3): p. 288-296.
6. Kuo, A.D., *The six determinants of gait and the inverted pendulum analogy: A dynamic walking perspective.* Human Movement Science, 2007. **26**(4): p. 617-656.
7. Winter, D.A., *Biomechanics of Human Movement*. 1979: John Wiley & Sons, Inc.

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