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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1 Introduction

There are two main types of gait modelling: simple link-segment and complex, anatomically accurate, musculoskeletal ones.

The simple models usually consist of rigid beams and masses that are given initial conditions and their kinematic and kinetic behaviour is assessed [1]. Some models incorporate springs and dampers [2].

The complex models, such as that of Anderson and Pandy [3, 4] consider multiple degrees of freedom and the forces applied by different muscles over the gait cycle.

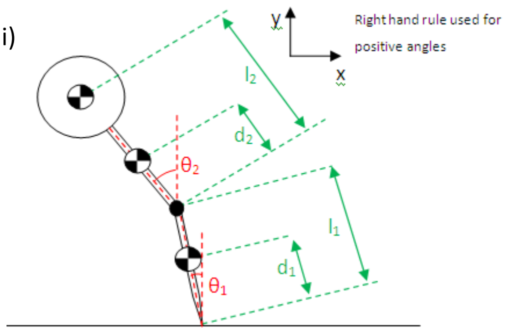
An interesting point to note is that complex models tend to be of active walking, involving muscle action, whereas simple models have been either active or passive.

There seems to be justification for incrementally increasing the complexity of 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.

2 Method

(i)



(ii)

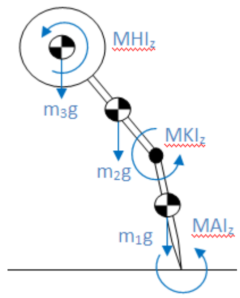


Figure 1: Schematics of the double inverted pendulum model showing (i) kinematic and (ii) kinetic properties

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. 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.

3 Results

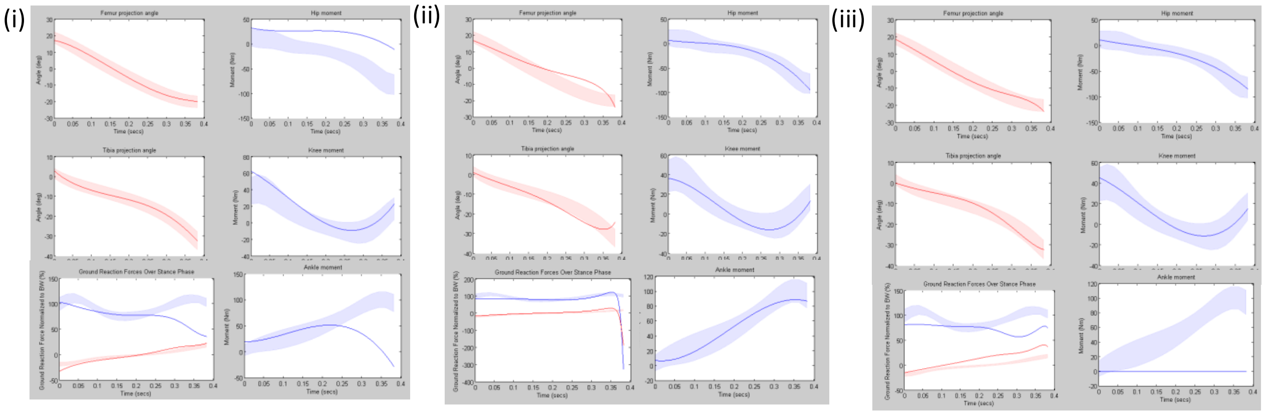


Figure 2: Results of simulations (i) matching kinematic properties only (ii) matching both kinematic and kinetic (iii) no ankle moment applied

4 Discussion

It has been shown that when the model is programmed to match kinematics only, the match for kinetic data is poor. By programming the model to match both kinematic and kinetic data curves, the correlation is better and, consequently, the simulated horizontal and vertical ground reaction force components also correspond to the empirical data more closely.

When there is no ankle moment applied, although good matches with kinematic data and the hip and knee moment curves are achieved, the ground reaction force prediction, in particular its vertical component, is detrimentally affected.

However, even the best results this model produces stray from the empirical data towards the end of single stance, where heel rise would occur. This particularly affects the horizontal and vertical components of the ground reaction force. This highlights the necessity of the addition of a foot to the model in order to replicate the empirical results fully.

In conclusion, foot and ankle mechanisms, play a major role in gait prediction during late single stance and optimisation techniques should consider kinetic, as well as kinematic properties in their cost function in order to achieve the best correlation.

References

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