**Title:**

# AN APPROPRIATELY COMPLEX BIOMECHANICAL MODEL OF RUNNING

**Abstract: (Your abstract must use 10 point New Times Roman style and must fit into the box. Do not enter author details)**

**Introduction**: Mathematical models of running have the potential to provide insight into how and why humans run the way they do. Existing models can generally be categorised as either simple or complex. The simple models often use spring to model the elastic storage and return of energy [1, 2] and are used to explore the fundamental mechanics of movement. On the other hand, the complex models often aim to model the individual components of the musculoskeletal system, using musculotendon actuators and complex activation dynamics, and hence understand the way in which the individual muscles contribute to the movement [3].

**Research Question**: What level of model complexity is required to describe the biomechanics of normal distance running?

**Methods**: A series of three models (Figure 1), each with an increasing level of complexity, were developed using OpenSim. Forward simulations of each of the models were compared to experimental data. Model 1 (spring mass model), consisted of a point mass representative of the body's centre of mass (CoM) connected to a fixed point on the ground via a massless linear spring of constant stiffness. Model 2 introduced a knee joint. A massless torsional spring connected two weighted segments and ground contact was modelled using a point constraint. Model 3 introduced a third segment and thus an ankle joint. Pin joints with torsional springs connected the segments and again ground contact was modelled using a point constraint.

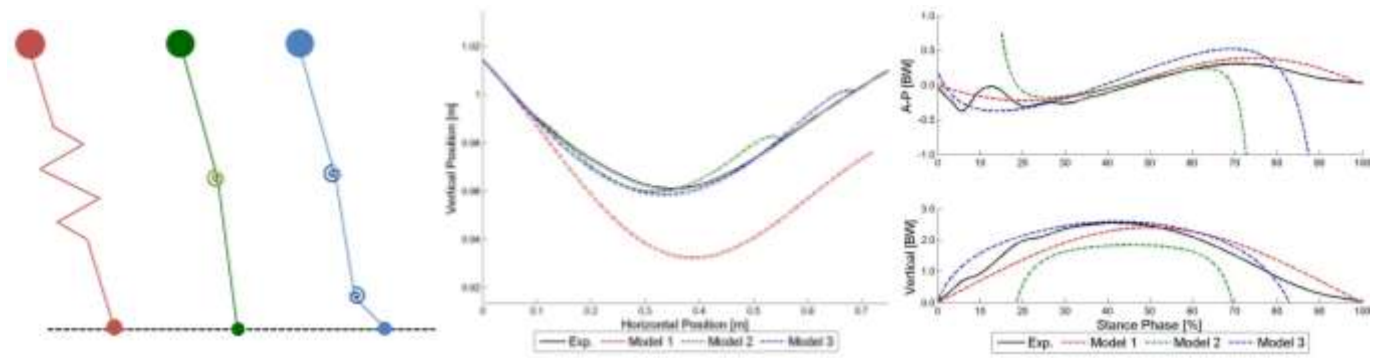


Figure 1 – Left: Series of models. Middle: CoM trajectories. Right: Ground Reaction Forces.

**Results**: Agreement between experimental data and model simulations improved as the complexity increased. With Model 1, the mean(SD) RMSD between the CoM trajectories were 29(8), 27(7), 25(6) and 23(7) mm at speeds 1 – 4, respectively. Peak vertical displacement and peak anterior-posterior ground reaction force (GRF) were overestimated, whereas the peak vertical GRF was underestimated. Geometry restrictions with Model 2 meant only the middle ~50% of stance could be modelled. This middle portion matched well with the experimental CoM trajectory ($RMSD_{CoM}$ = 5(2), 11(11), 15(15) and 14(20) mm at speeds 1 – 4, respectively). However, interestingly there was poorer agreement between predicted and experimental GRFs than with Model 1. Model 3 resulted in reasonable agreement between both the kinematics and the kinetics, mean(SD) RMSD between the CoM trajectories were 16(15), 14(8), 13(6) and 13(5) mm at speeds 1 – 4, respectively.

**Discussion**: These models provide potential rationales for the mechanical characteristics that contribute to how and why people run the way they do. For example, for the knee model, the agreement in the kinematics suggests that a passive torsional spring is sufficient to replicate mid-stance of running, but that to replicate early and late stance a combination of ankle and knee mechanisms is required.

**References**: 1) McMahon TA, et al, *J Biomech*, **23**: 65 - 78, 1990; 2) Bullimore SR & Burn JF, *J Theor Biol*, **248**: 686 - 695, 2007 ; 3) Hamner SR, et al, *J Biomech*, **43**: 2709 - 2716, 2010