

# DETERMINING VERTICAL GROUND REACTION FORCES WITHOUT A FORCE PLATFORM USING A MASS-SPRING-DAMPER MODEL

Ross H. Miller<sup>1,2</sup>, Graham E. Caldwell<sup>1</sup>, and Timothy R. Derrick<sup>2</sup>

<sup>1</sup>Department of Kinesiology, University of Massachusetts Amherst, Amherst, MA, USA

<sup>2</sup>Department of Health and Human Performance, Iowa State University, Ames, IA, USA

Email: rhmiller@kin.umass.edu Web: http://www.umass.edu/sphhs/kinesiology

## INTRODUCTION

The mechanics and stiffness characteristics of the body during running are often described by mass-spring (MS) models (Farley & Gonzalez, 1996) or mass-spring-damper (MSD) models (Derrick *et al.*, 2000; Nigg & Liu, 1999). Using models to generate ground reaction forces (GRF) could be beneficial when no force measurement is possible. While MS models can replicate the active mid-stance vertical GRF peak (Morin *et al.*, 2005), MSD models can also produce the passive impact peak present in heel-toe running (Derrick *et al.*, 2000). The feasibility of using an MSD model to predict GRF in the absence of a force platform depends on how well MSD parameters can be predicted from simple measurements that can be made outside the laboratory. Our purpose was to investigate the ability of an MSD model to produce model GRF (*MGRF*) that replicate experimental GRF (*EGRF*) without using a force platform. MSD parameters were predicted by correlating kinematic and anthropometric measurements with optimized parameters.

## METHODS

*EGRF* were collected for ten healthy young subjects running over a force platform at their preferred pace for seven trials each. Joint kinematics were computed from reflective markers on the dominant leg. Each subject's kinematics and *EGRF* were averaged across trials. *MGRF* were generated with a MATLAB-based MSD model (Derrick *et al.*, 2000; Fig. 1). The

lower mass  $M_2$  represents the effective mass of the body accelerated at impact. The upper mass  $M_1$  is the remainder of the body's mass.

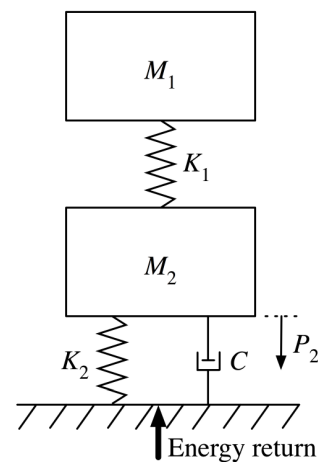


Figure 1. The MSD model used to generate GRF.

For each subject, stiffness parameters ( $K_1$  and  $K_2$ ) and the initial lower mass height ( $P_2$ ) were optimized using a genetic algorithm to minimize the mean square error and timing errors between *MGRF* and *EGRF*. Optimal MSD parameters were then correlated by multiple linear regression with eight anthropometric and kinematic measures: sex, height, weight, leg length, thigh length, running speed, knee flexion angle at heel-strike, and knee flexion range of motion (ROM) during stance. GRF generated by parameters predicted by regression (*RGRF*) were compared to *EGRF* and *MGRF*.

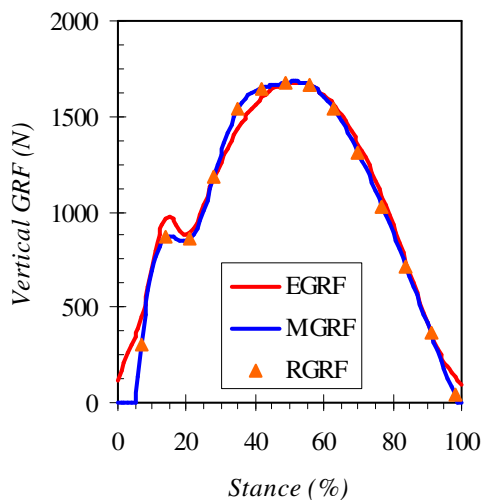
## RESULTS & DISCUSSION

The damping coefficient  $C$ , energy return, effective mass, and error between *MGRF*

and *EGRF* were comparable to previous MSD models (Derrick *et al.*, 2000). Linear regression predicted strong correlations for  $K_1$ ,  $K_2$ , and  $P_2$  ( $R^2 = 0.99, 0.95$ , and  $0.99$ , respectively) between optimal MSD parameters and the anthropometric and kinematic measures. Table 1 shows the average parameters from optimization and regression. Height, weight, and knee flexion ROM were the most sensitive regression parameters. Leg length was a sensitive parameter for  $P_2$ . *MGRF* and *RGRF* profiles were nearly identical for all subjects. Figure 2 shows *EGRF*, *MGRF*, and *RGRF* profiles for a representative subject.

**Table 1.** Optimal and regressed MSD parameters.

	$K_1$ (N/m)	$K_2$ (N/m)	$P_2$ (mm)
Optimization	14557	104565	8.45
Regression	14556	104612	8.46



**Figure 2.** *EGRF*, *MGRF*, and *RGRF* curves.

Results indicate that the MSD model with parameters predicted by regression can accurately represent experimental GRF without kinetic measures. Previous research that modeled GRF without kinetic data depended on stance time, which is difficult to measure without a force platform or motion capture system (Morin *et al.*, 2005). The MSD model with parameters estimated by regression can generate relatively

accurate GRF using lower extremity anthropometrics and sagittal knee kinematics, quantities easily measured by anthropometry and electrogoniometry.

The MSD model had difficulty matching the GRF profile near heel-strike and toe-off (Fig. 2) and typically provided a better fit between *EGRF* and *MGRF* for the mid-distance peak (average error of 3%) compared to the impact peak (average error of 10%). Model performance can be improved by using a cost function that emphasizes peak magnitudes, or by including wobbling masses (Nigg & Liu, 1999).

## SUMMARY & CONCLUSIONS

Vertical GRF during running were determined using a mass-spring-damper (MSD) model. By optimizing the MSD parameters, the model could generate GRF that closely matched experimental data. Model parameters were strongly correlated with data that are easy to measure without force platforms or motion capture systems. Therefore model parameters could be estimated from regression and used to determine vertical GRF outside a laboratory setting. The next step, predicting the anterior-posterior GRF by a Fourier series model, has shown promising early results.

## REFERENCES

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