# MODELING OF THE FOOT-ANKLE SYSTEM IN NATURAL STANDING POSITION USING A FOUR DEGREE-OF-FREEDOM LUMPED PARAMETER MODEL

***Katie A. Goggins[1,2,3], Delphine Chadefaux[4,5], Marco Tarabini[4], W. Brent Lievers[2,3], Marc Arsenault[3], & Tammy R. Eger[1,2]**

**[1]Centre for Research in Occupational Safety and Health, Sudbury, ON, Canada**
**[2]School of Kinesiology and Health Sciences, Laurentian University, Sudbury, ON, Canada**
**[3]Bharti School of Engineering, Laurentian University, Sudbury, ON, Canada**
**[4]Department of Mechanics, Politecnico di Milano, Lecco, Italy**
**[5]Insitut de Biomécanique Humaine Georges Charpak, Université Paris 13 Nord, Villetaneuse, France**

## Introduction

Models designed to simulate the body's response to vibration exposure reduce participant exposure times and risk, and are an effective means of testing possible solutions to reduce occupational exposure. Foot-transmitted vibration (FTV) has traditionally been studied in the context of whole-body vibration, but recent literature suggests it warrants separate consideration. It is hoped that improved FTV predictive abilities can one day be used for interventions to reduce the incidence and severity of vibration induced white toes. This study aims to assess whether a three-segment model (two foot segments, one body segment) is capable of predicting the frequency response of the foot and ankle in three standing positions from 10-60Hz (i.e. occupational exposure frequencies).

## Methods

The transmissibility responses at the ankle, midfoot, and toes [1, 2], (Goggins *et al.*, 2018; Goggins *et al.*, 2019), from FTV exposure between the frequencies of 10-60 Hz, were used as the reference functions. Three center of pressure (COP) positions were considered: forward, natural, backward. A planar lumped parameter (LP) model with 4 degrees-of-freedom (DOF), which idealized the foot-ankle-system as a truss structure supporting half of the total body mass (Figure 1), was used to replicate the dynamic behaviour [3] (Ji, Zhou and Zhang, 2013). For the full linearised dynamic model, refer to Goggins et al. [4] (Goggins *et al.*, 2021).

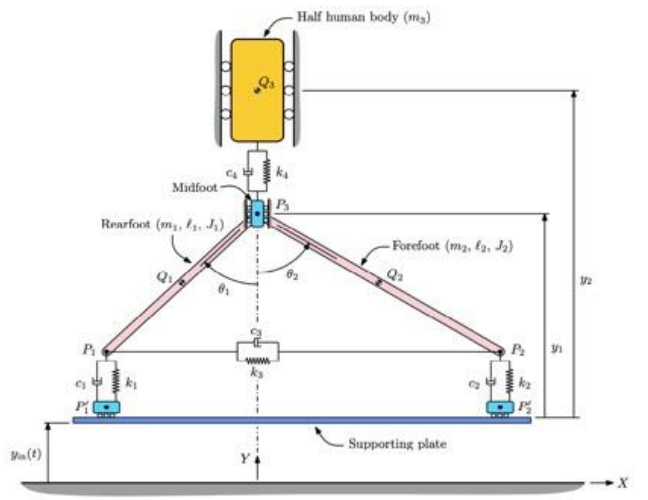


Figure 1: Truss structure model of the foot-ankle-system [4].

## Results

The natural COP and forward COP positions resulted in reasonable model results (Figure 2), Unfortunately, the model did not sufficiently capture the backward COP position transmissibility response, particularly the response at the ankle.

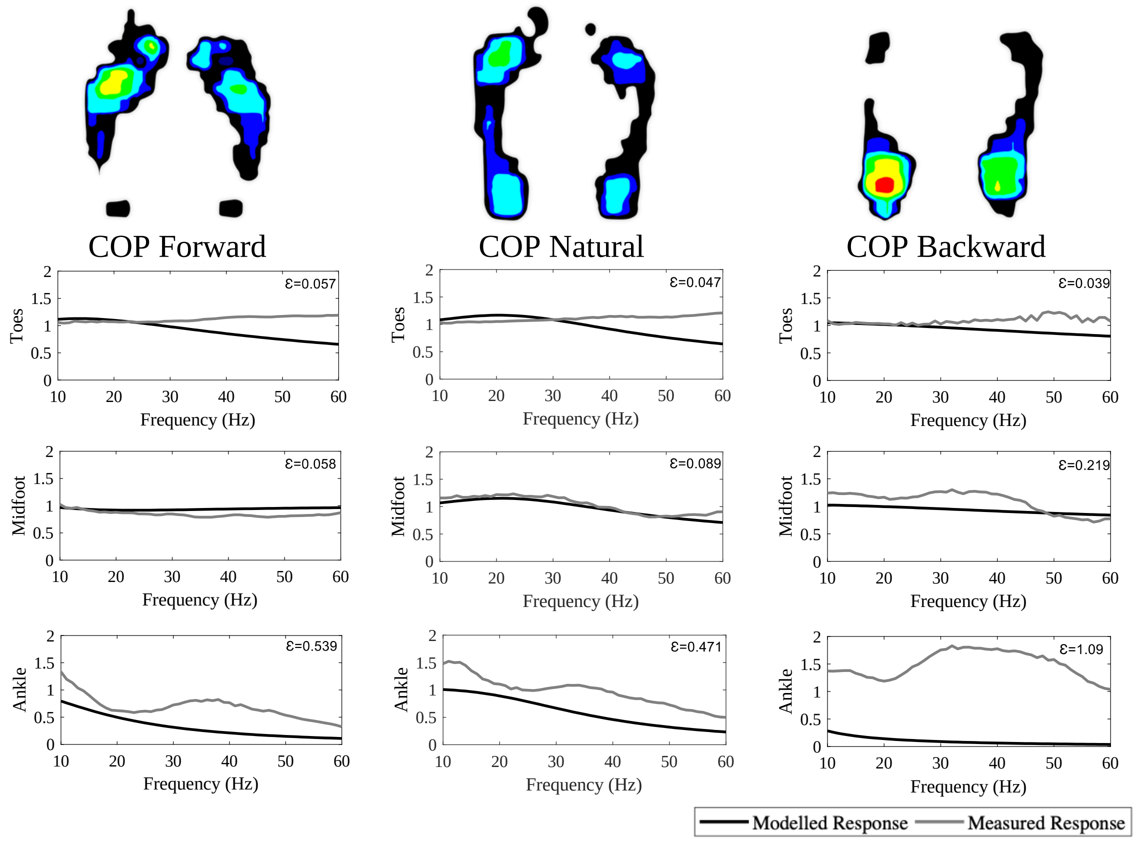


Figure 2: Modelled (black) and measured (grey) transmissibility response from 10-60Hz in three centre of pressure positions. Images reproduced from Goggins et al. [4]. (Goggins *et al.*, 2021).

## Discussion

While the current work represents a useful initial model of the vibration response, further refinements are needed to fully capture the foot's behaviour under a variety of loading scenarios. These results suggest that properly modelling of the soft tissue of the hindfoot (i.e. the heel fat pad) needs to be a priority. Future LP models could also add segments for the toes, divide the midfoot and ankle into more components, and include segments for the lower limb. Additionally, components can be added to test the effects of various materials underneath the foot (insoles or boots) and determine what thickness, stiffness, and damping characteristics for these materials would be the most effective.

## References

[1] Goggins, K., Tarabini, M., Lievers, W. B. and Eger, T. (2018) 'Biomechanical response of the human foot when standing in a natural position exposed to vertical vibration from 10-200 Hz', *Ergonomics,* 62(5), pp. 644-656.

[2] Goggins, K., Tarabini, M., Lievers, W. B. and Eger, T. (2019) 'Standing centre of pressure alters the vibration transmissibility response of the foot', *Ergonomics,* 62, pp. 1202-1213.

[3] Ji, T., Zhou, D. and Zhang, Q. (2013) 'Models of standing human body in vertical vibration', *Structures and Buildings*, 166(SB7), pp. 367-378.

[4] Goggins, K. A., Chadefaux, D., Tarabini, M., Arsenault, M., Lievers, W. B. and Eger, T. (2021) 'Four degree-of-freedom lumped parameter model of the foot-ankle system exposed to vertical vibration from 10 to 60 Hz with varying centre of pressure conditions', *Ergonomics*, pp. 1-15.