University of Cincinnati National Institute for Occupational Safety and Health (NIOSH)-supported Education and Research Center (ERC)

FREE AND OPEN TO THE PUBLIC

12th Annual 2011 Pilot Research Project (PRP) Symposium

Thursday, Oct. 13, 1 pm-5:15 pm
Friday, Oct. 14, 8 am-12:15 pm
Kehoe Auditorium, Kettering Laboratory

Supported by NIOSH Grant #T42-OH008432

Effect of Aging on Human Postural Control: A Predictive Modeling Approach

Carson Willey

Amit Shukla

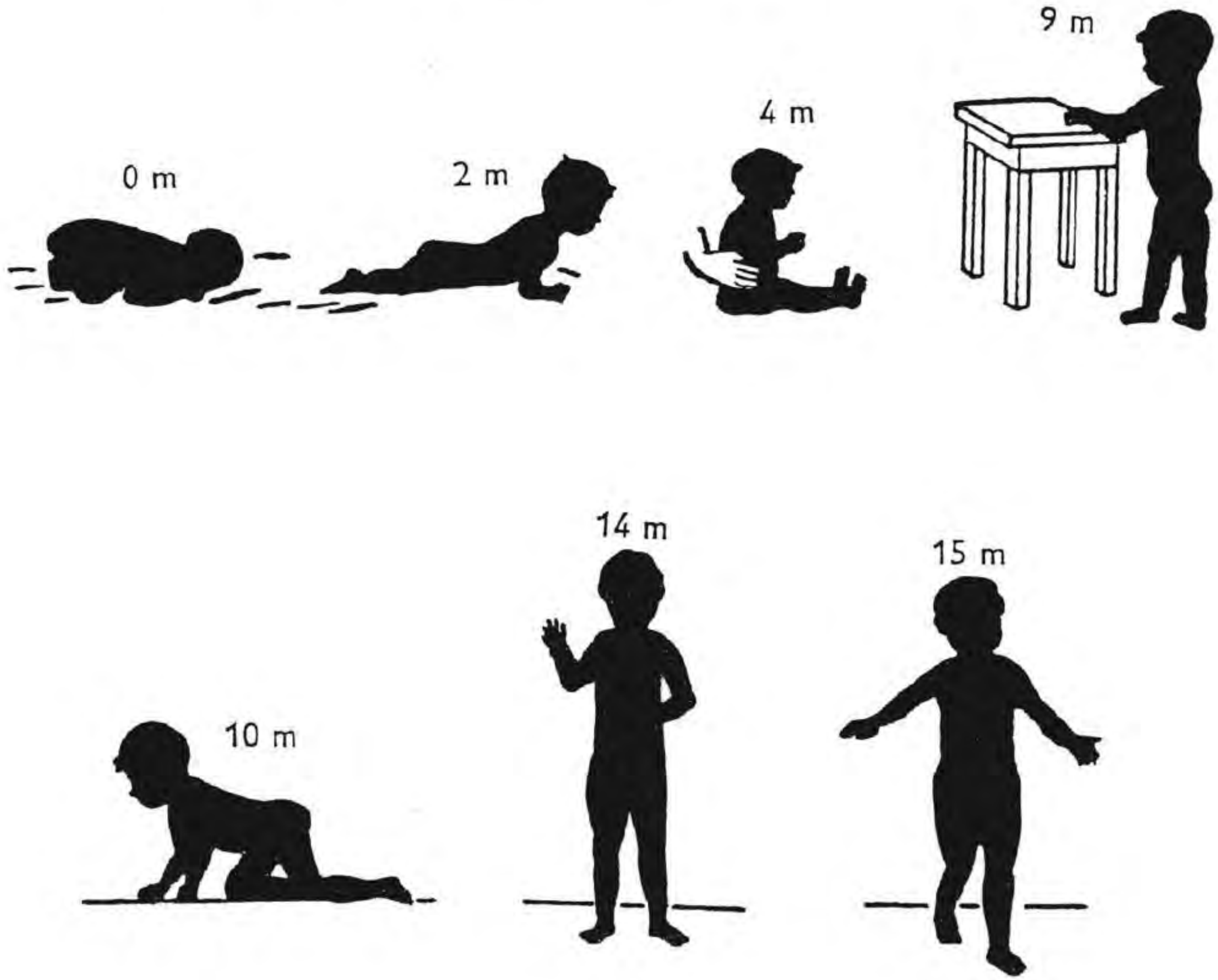
Renu Sah

MIAMI UNIVERSITY
1809
OXFORD OHIO

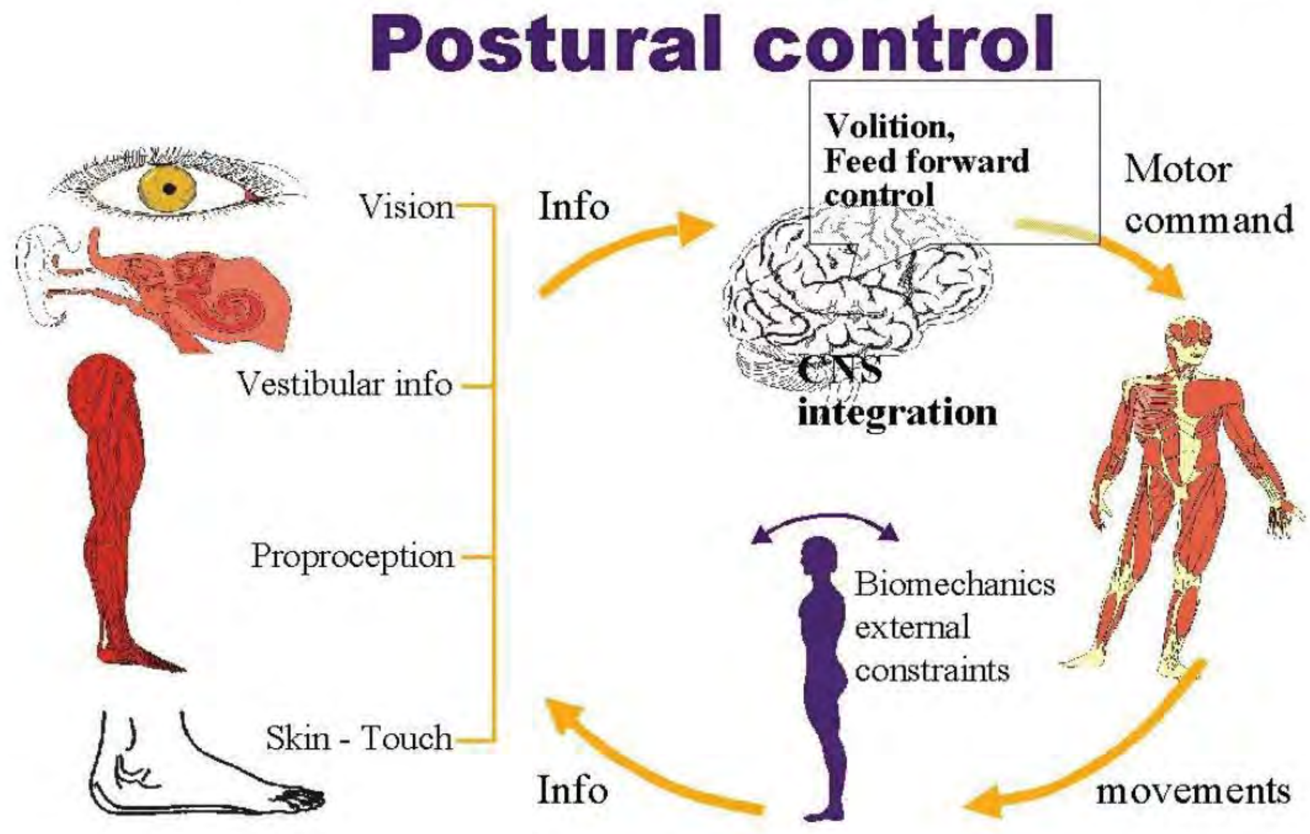
Outline

- Balance and Aging
- Modeling Balance: Dynamics and Control
- L-2 Norm as a balance metric
- Parametric Studies
- Results and Discussion
- Future Work

Balance and Posture



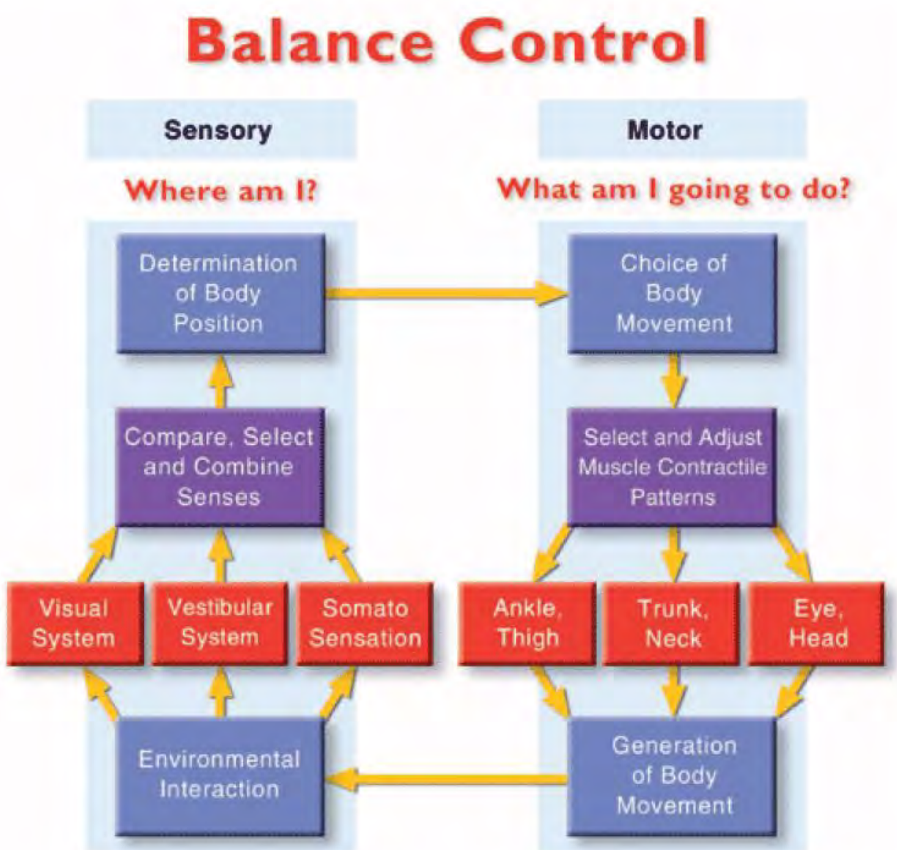
Human Postural Control: Why?



Courtesy: Swedish Medical Research Council

MIAMI UNIVERSITY OXFORD OHIO

Human Postural Control



Jacobson GP, Newman CW, Kartush JM (1993). *Handbook of Balance Function Testing*. Mosby Year Book, St Louis.

MIAMI UNIVERSITY
OXFORD OHIO

Human Postural Control

Imbalance could be due to:

– cardiovascular dysfunction,

– visual disorientation,

– inadequate limb proprioception,

– vestibular signals or dysfunction.

Complex Nature of Balance Problems

MIAMI UNIVERSITY
OXFORD OHIO

Human Postural Control: Medical Causes

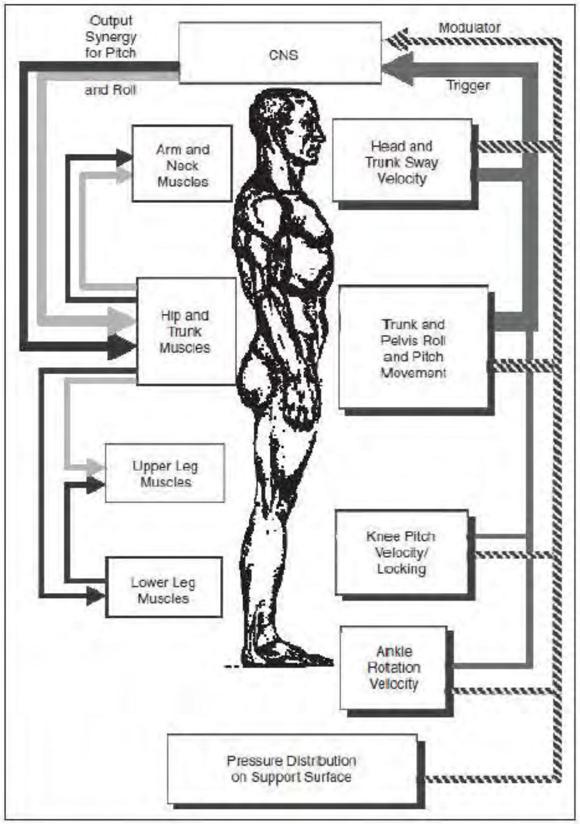
- Aging and Balance Dysfunction
  - Parkinson's Disease
  - Accumulated Injuries
  - Ear infections
  - Diabetes
  - Others

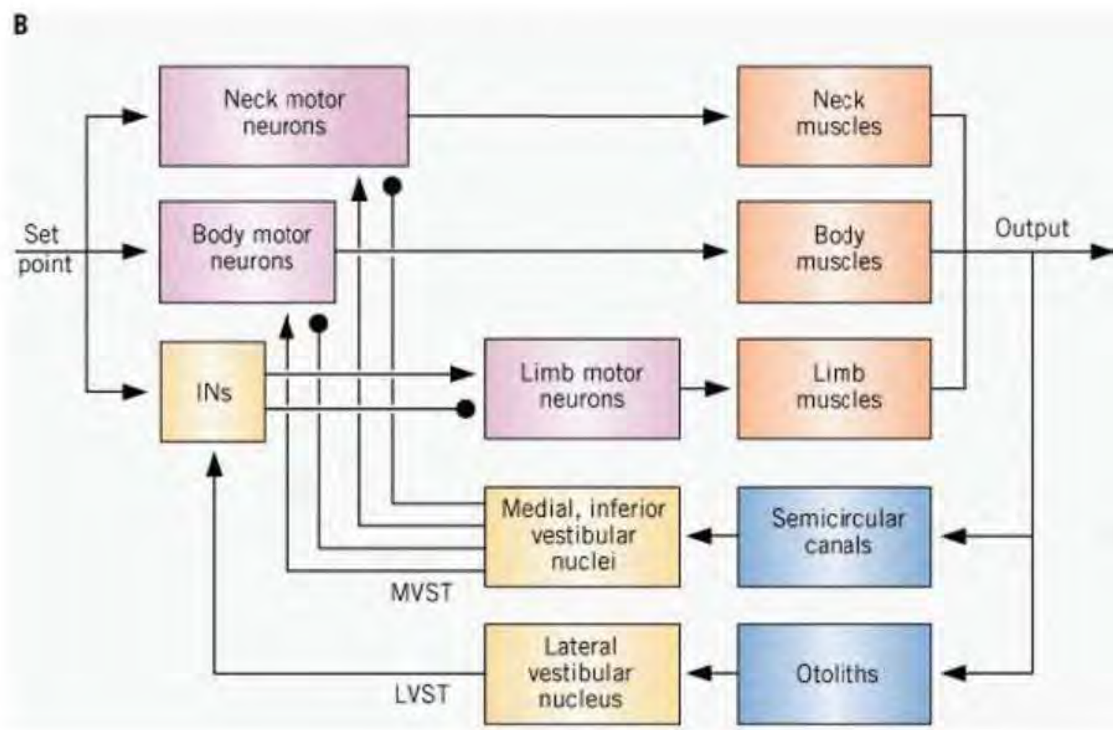
Whether balance disorders result from combinations of subtle problems or obvious disease, clinical studies indicate that elderly fallers are different from their healthy age-matched counterparts and require medical treatment to maintain their functional independence and quality of life.

MIAMI UNIVERSITY
OXFORD OHIO

Dynamics and Control

Multiple sensor-multiple inputs

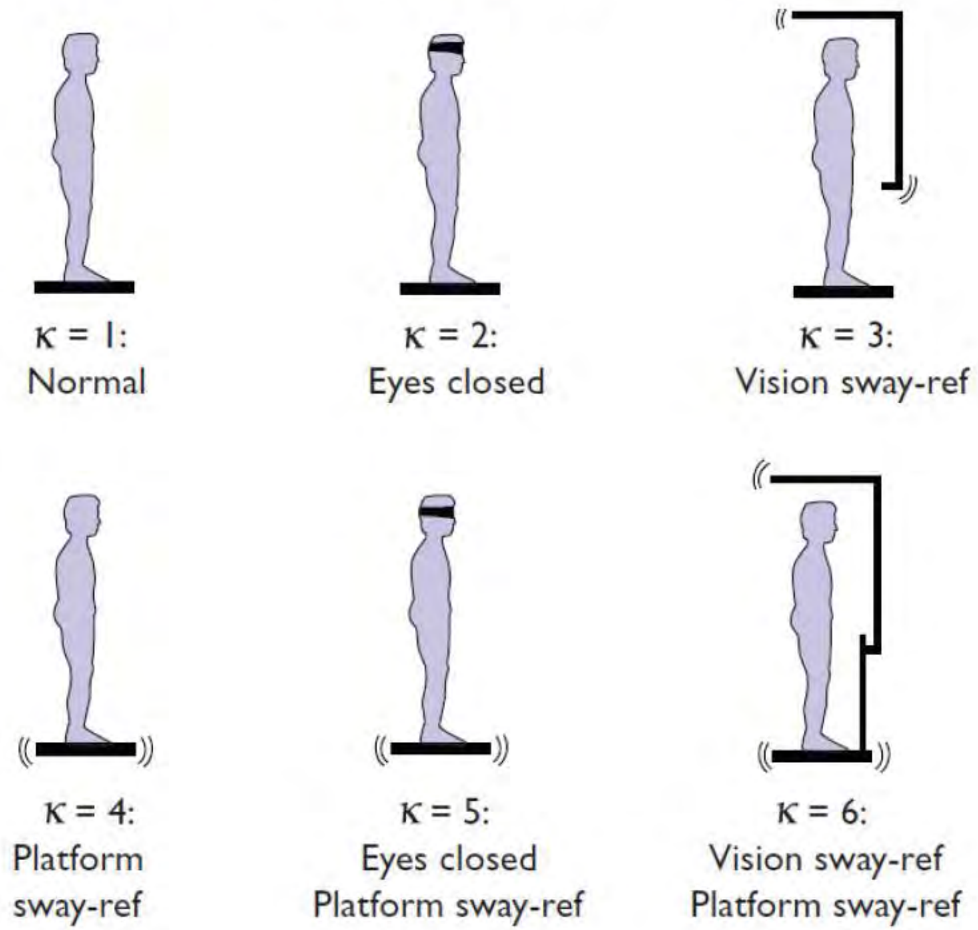




MIAMI UNIVERSITY
OXFORD OHIO

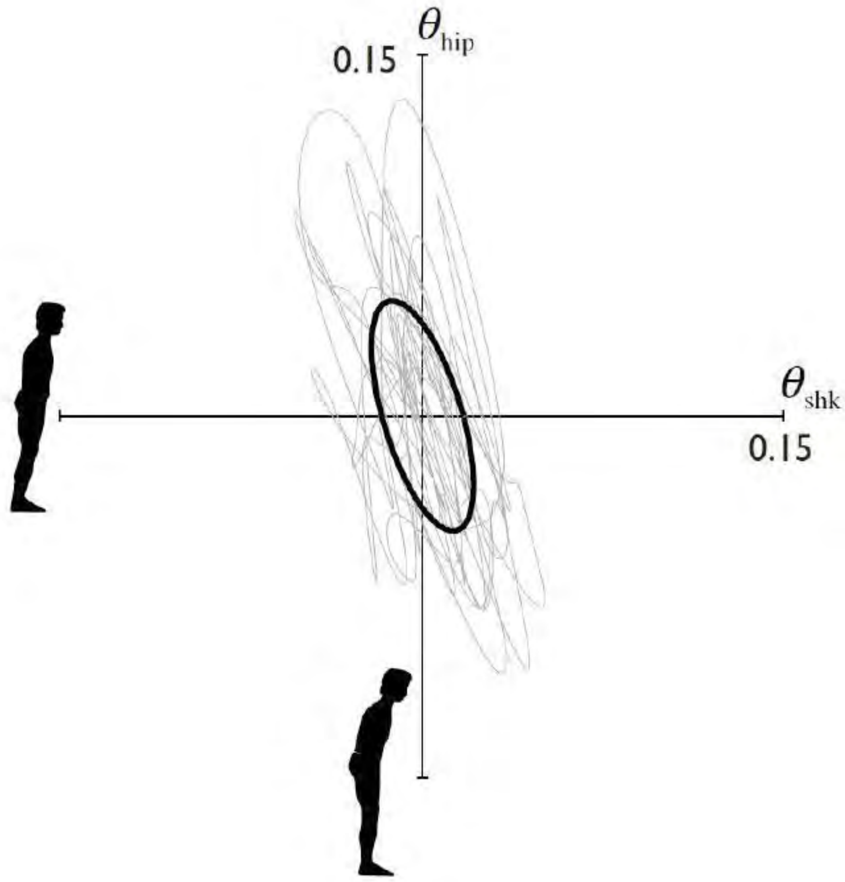
Dynamics and Control

Dynamics posturography with sensory condition number (k)



Dynamics and Control

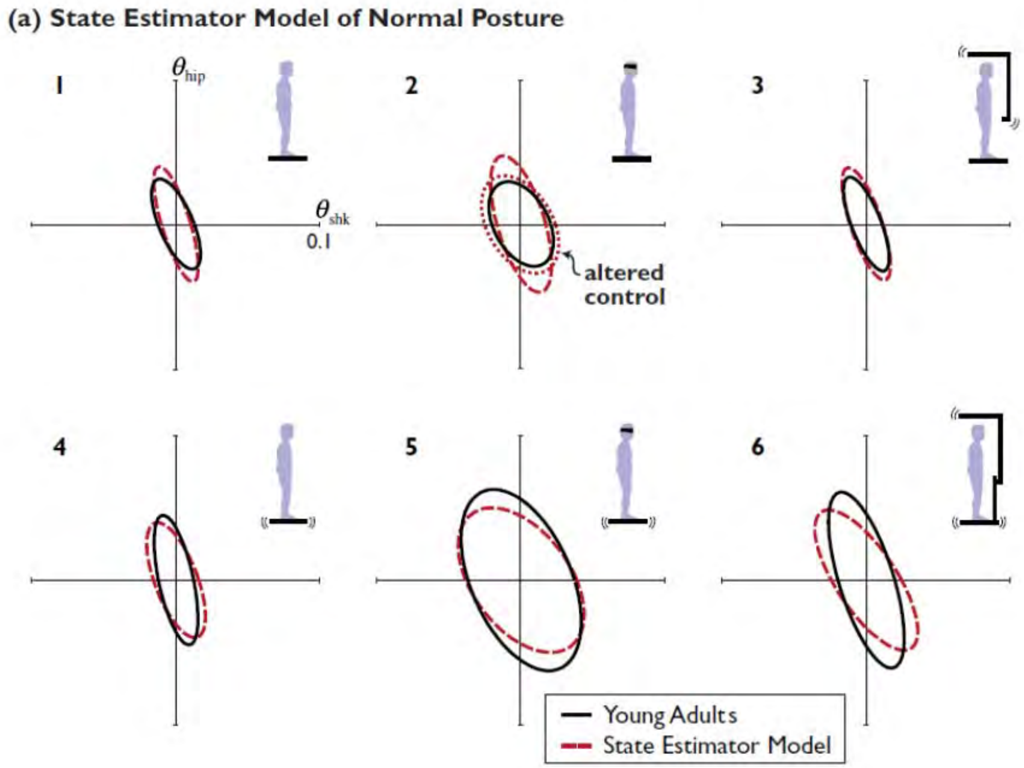
Covariance data: shank angle vs. hip angle



MIAMI UNIVERSITY
OXFORD OHIO

Dynamics and Control

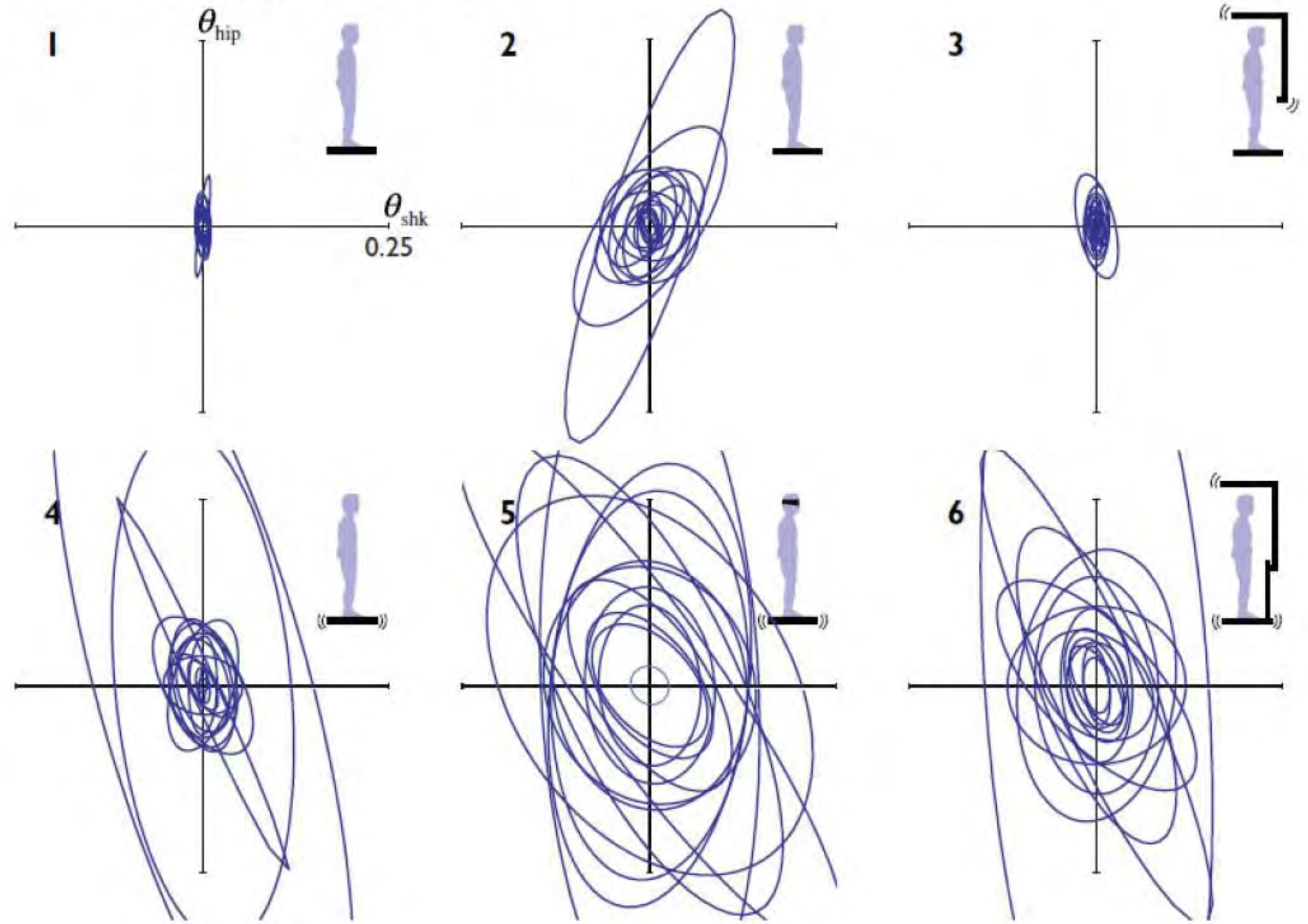
Covariance data:shank angle vs. hip angle



Kuo A D 1995 An optimal control model for analyzing human postural balance *IEEE Trans. Biomed. Eng.* **42** 87–101

Dynamics and Control

Older Adult Subjects (N = 15)



MIAMI UNIVERSITY
OXFORD OHIO

The One Degree of Freedom Model

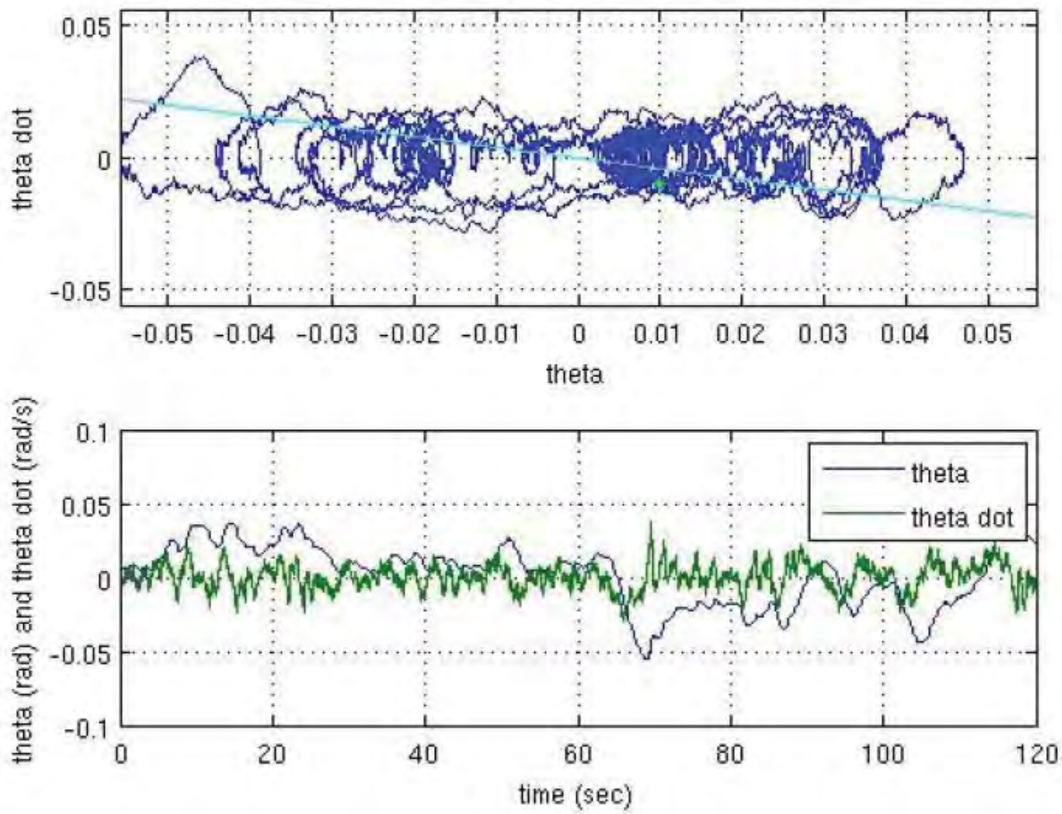
Parameter	Value	Units
m	80	kg
g	9.81	m/s^2
h	1	m
K	.25 mgh	N/rad
B	4	$N/rad*s$
P	.8 mgh	N/rad
D	14	$N/rad*s$
a	-.4	$rad/s/rad$
r	.004	

$$I\ddot{\theta} = mgh\sin(\theta) - T$$
$$T = K\theta + B\dot{\theta} + P\theta_\Delta + D\dot{\theta}_\Delta$$
$$\theta_\Delta = \theta(t-\tau)$$
$$\dot{\theta}_\Delta = \dot{\theta}(t-\tau)$$
$$\sqrt{\dot{\theta}_\Delta^2 + {\theta_\Delta}^2} < r \text{ and } \theta_\Delta(\dot{\theta}_\Delta - a\theta_\Delta) > 0$$

[1] Y. Asai, Y. Tasaka, K. Nomura, T. Nomura, and M. Casadio, “A model of postural control in quiet standing: Robust compensation of delay-induced instability using intermittent activation of feedback control,” PLoS ONE, vol. 4, no. 7, 2009.

MIAMI UNIVERSITY
OXFORD OHIO

One DOF Model Output



The Two Degree of Freedom Model

Pendulum Dynamics

$$\ddot{\theta}_1(2\alpha - (\delta^2)/(2\beta)\cos(\theta_1-\theta_2)^2) = -(\delta^2)/(2\beta)\dot{\theta}_1^{\,2}\sin(\theta_1-\theta_2)\cos(\theta_1-\theta_2)$$
$$-(\delta\zeta)/(2\beta)\sin(\theta_2)\cos(\theta_1-\theta_2) - \delta\dot{\theta}_2^{\,2}\sin(\theta_1-\theta_2) + \gamma\sin(\theta_1) - T_1$$
$$\ddot{\theta}_2(2\beta - (\delta^2)/(2\alpha)\cos(\theta_1-\theta_2)^2) = (\delta^2)/(2\alpha)\dot{\theta}_2^{\,2}\sin(\theta_1-\theta_2)\cos(\theta_1-\theta_2)$$
$$-(\delta\gamma)/(2\alpha)\sin(\theta_1)\cos(\theta_1-\theta_2) + \delta\dot{\theta}_1^{\,2}\sin(\theta_1-\theta_2) + \zeta\sin(\theta_2) - T_2$$

Constants

$$\alpha = (m_1 {l_1}^2)/8 + (m_2 {l_1}^2)/2 + I_1/2$$
$$\beta = (m_2 {l_2}^2)/8 + I_2/2$$
$$\gamma = (g m_1 l_1)/2 + g m_2 l_1$$
$$\zeta = (g m_2 l_2)/2$$
$$\delta = (m_2 l_2 l_1)/2$$
$$I_1 = (m_1 l_1^2)/12$$
$$I_2 = (m_2 l_2^2)/12$$

Controller Torques

$$T_1 = K_1\theta_1 + K_2(\theta_1-\theta_2) + B_1\dot{\theta}_1 + B_2(\dot{\theta}_1-\dot{\theta}_2) + P_1\theta_{1\Delta} + P_2(\theta_{1\Delta}-\theta_{2\Delta}) + D_1\dot{\theta}_{1\Delta}$$
$$+D_2(\dot{\theta}_{1\Delta}-\dot{\theta}_{2\Delta}) + \sigma\eta$$
$$T_2 = K_2(\theta_2-\theta_1) + B_2(\dot{\theta}_2-\dot{\theta}_1) + P_2(\theta_{2\Delta}-\theta_{1\Delta}) + D_2(\dot{\theta}_{2\Delta}-\dot{\theta}_{1\Delta}) + \sigma\eta$$

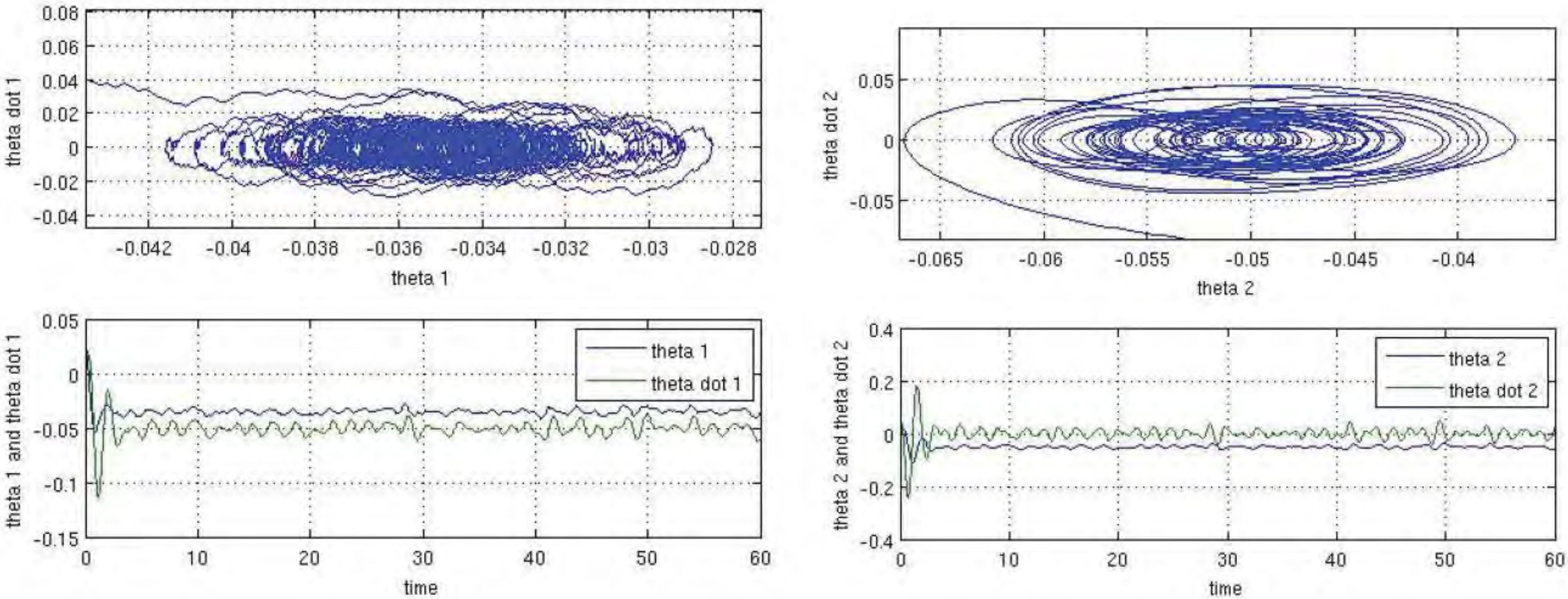
$$\theta_{j\Delta} = \theta_j(t-\tau)$$
$$\dot{\theta}_{j\Delta} = \dot{\theta}_j(t-\tau)$$

Intermittent Activation Conditions

$$\sqrt{\dot{\theta}_{1\Delta}^2 + {\theta_{1\Delta}}^2} < r \text{ and } \theta_{1\Delta}(\dot{\theta}_{1\Delta} - a\theta_{1\Delta}) > 0$$
$$\sqrt{(\dot{\theta}_{2\Delta}-\dot{\theta}_{1\Delta})^2 + (\theta_{2\Delta}-\theta_{1\Delta})^2} < r \text{ and}$$
$$(\theta_{2\Delta}-\theta_{1\Delta})((\dot{\theta}_{2\Delta}-\dot{\theta}_{1\Delta}) - a(\theta_{2\Delta}-\theta_{1\Delta})) > 0$$

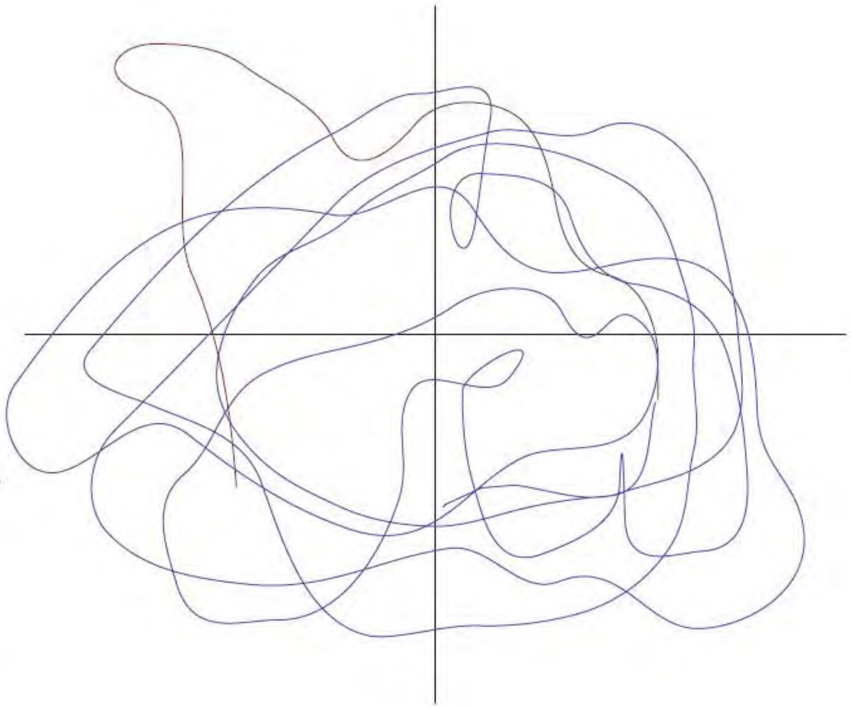
MIAMI UNIVERSITY
OXFORD OHIO

Two DOF Model Output



Average L_2 Norm Analysis

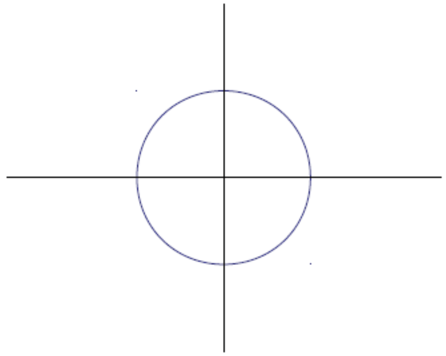
- As $t \rightarrow \infty$
- Case1 : Avg L_2 Norm < Ref L_2 Norm
- Case2 : Avg L_2 Norm ≈ Ref L_2 Norm
- Case3 : Avg L_2 Norm > Ref L_2 Norm
- Ref L2 is the average norm taken with respect to the delay history (red).
- Avg L2 Norm is the same measure taken with respect to the projected curve (blue).



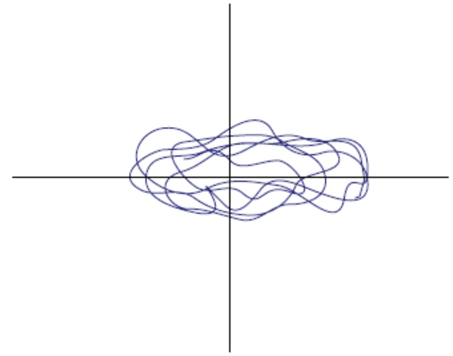
$$L_{2\ \mathrm{avg}} = \frac{1}{N} \sum_{i=1}^{N} L_i \text{ where } L_i = \sqrt{x_i^2 + y_i^2}$$

MIAMI UNIVERSITY
OXFORD OHIO

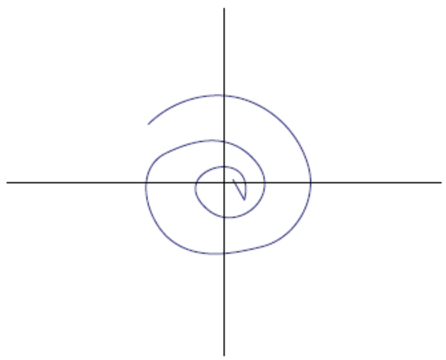
Average L_2 Norm Analysis



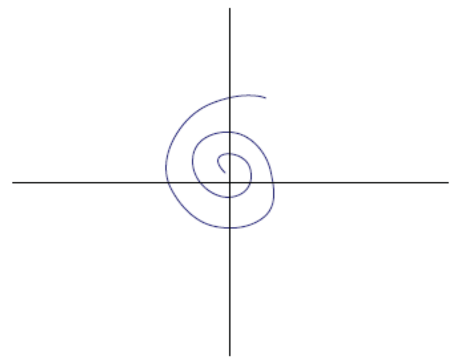
Case 2 : constant energy



Case 2 : realistic phase plot



Case 1 : Decreasing Energy

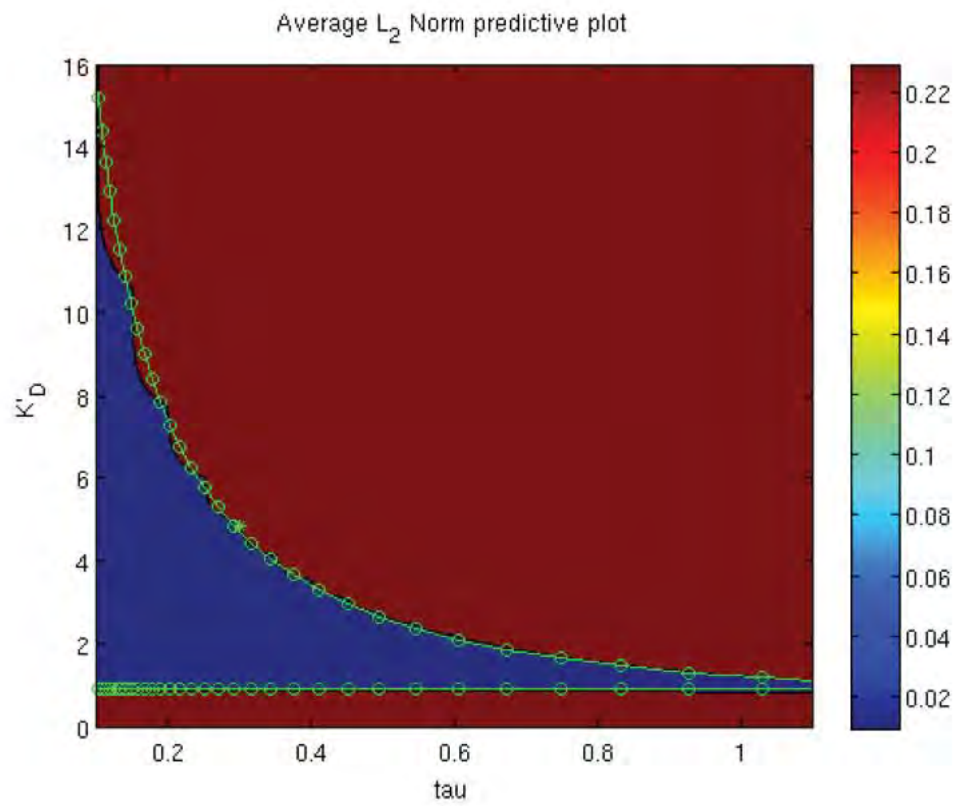


Case 3 : Increasing Energy

In this research

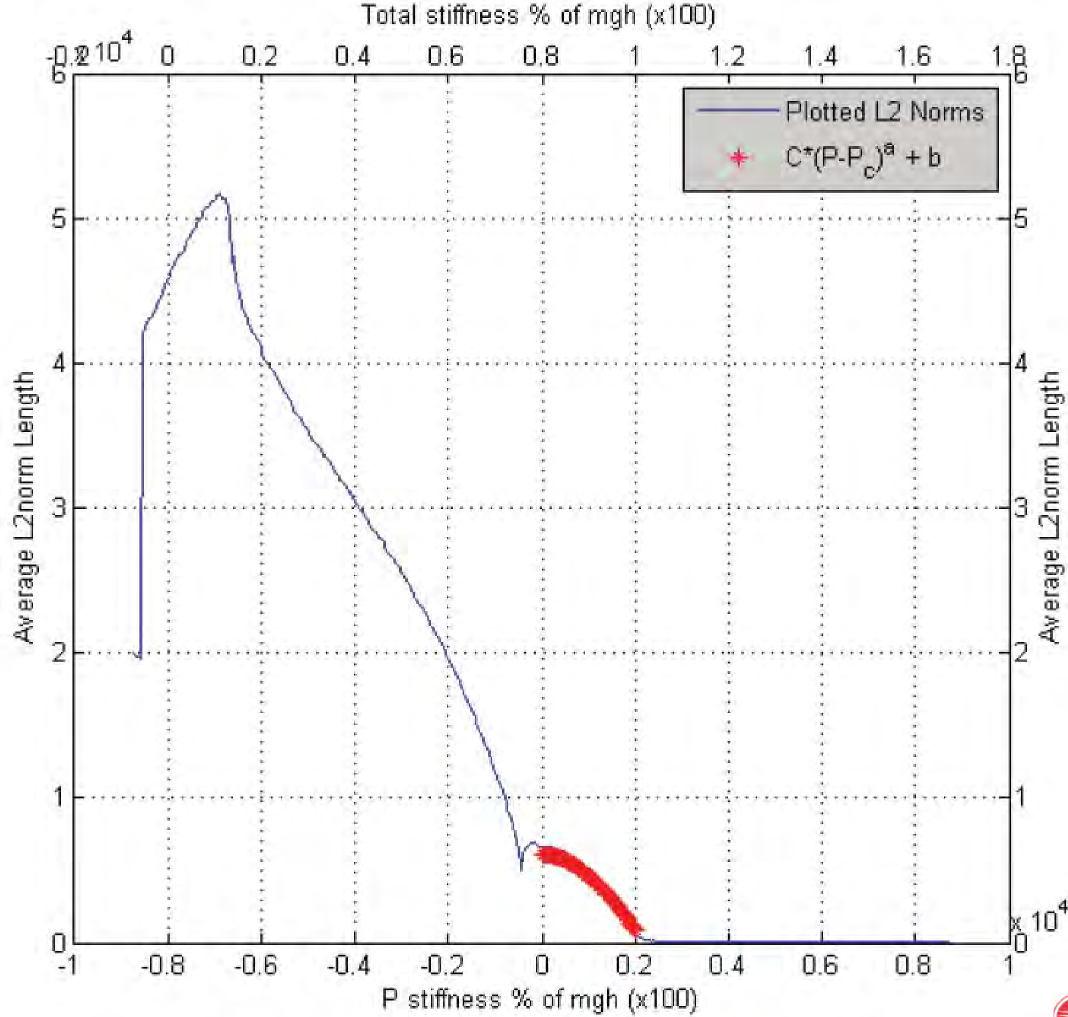
- Hypothesis 1: Aging can be modeled as change in parameters.
- Hypothesis 2: L2-Norm can be used as a balance metric.

Linear Stability Analysis of 1 DOF

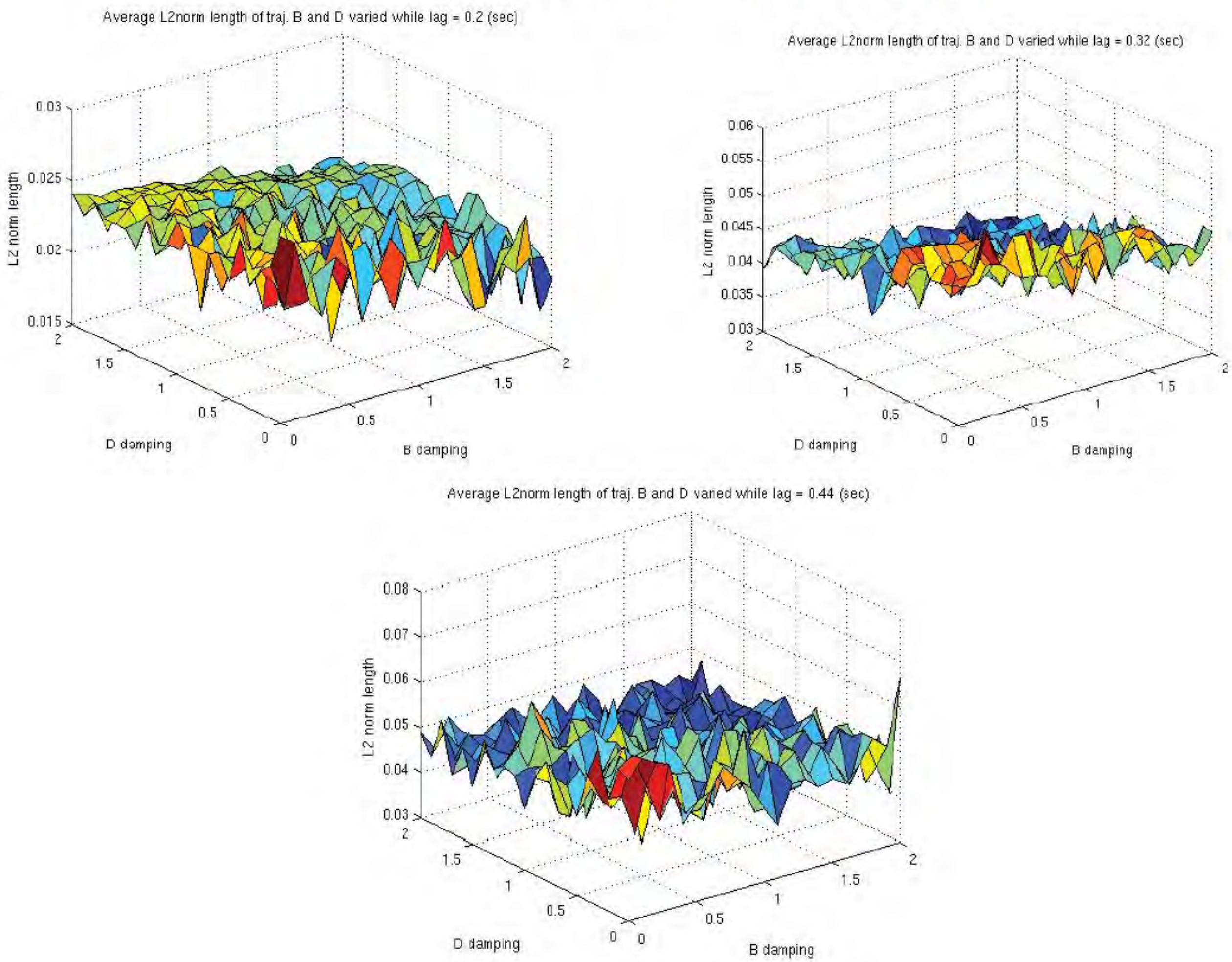


MIAMI UNIVERSITY
OXFORD OHIO

Parametric Study of One DOF Model

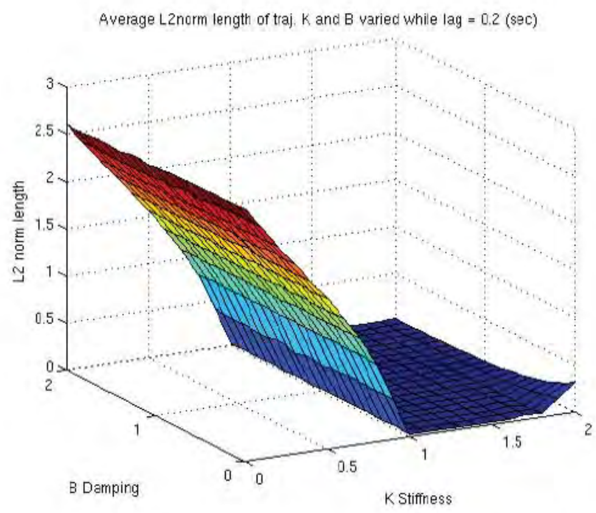


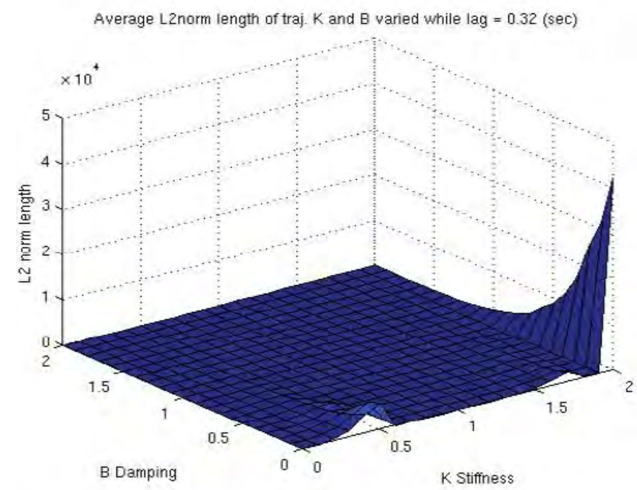
Parameter Combination Study of One DOF Model

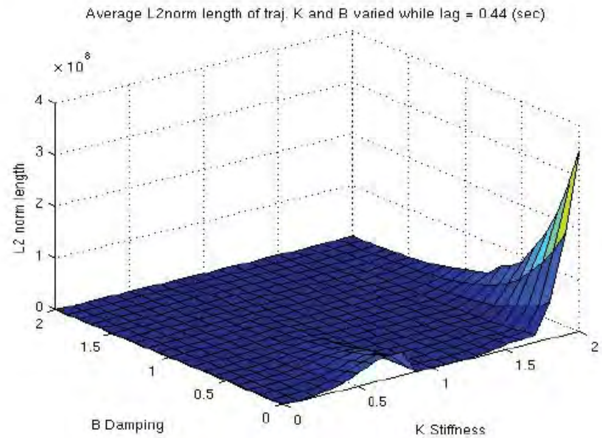


MIAMI UNIVERSITY
OXFORD OHIO

Parameter Combination Study of One DOF Model (cont'd)

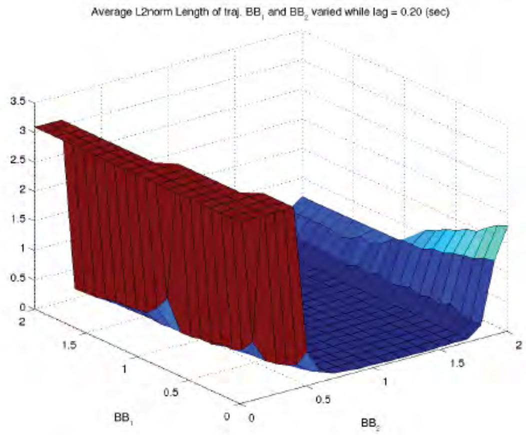


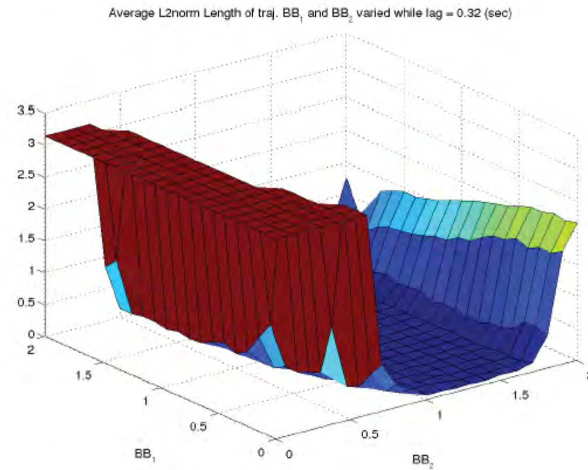


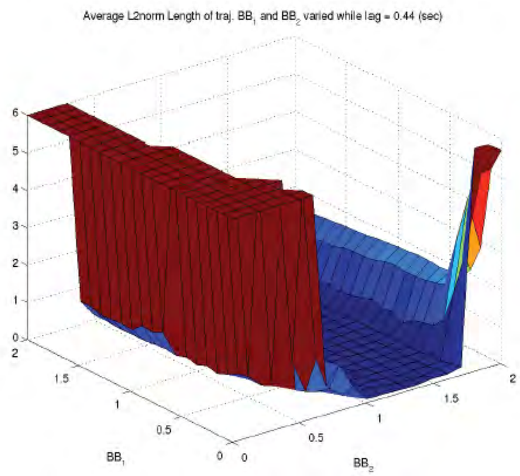


MIAMI UNIVERSITY
OXFORD OHIO

Parameter Combination Study of Two DOF Model



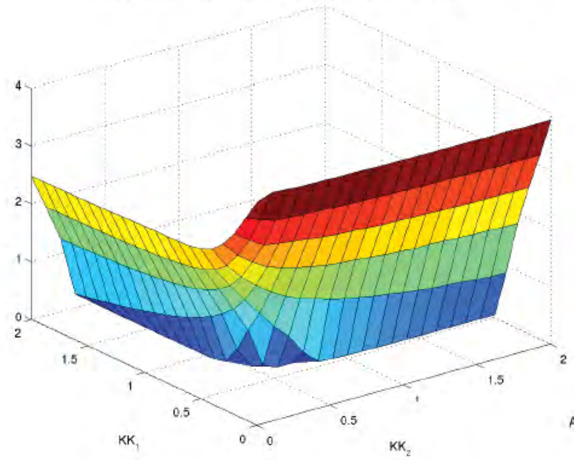




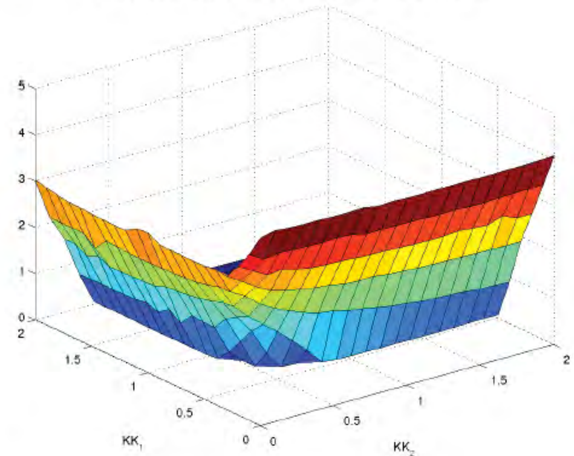
MIAMI UNIVERSITY
OXFORD OHIO

Parameter Combination Study of Two DOF Model (cont'd)

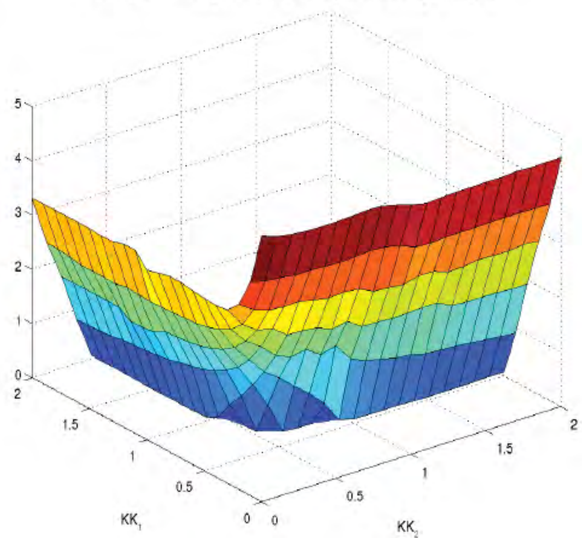
Average L2norm Length of traj. KK_1 and KK_2 varied while lag = 0.20 (sec)



Average L2norm Length of traj. KK_1 and KK_2 varied while lag = 0.32 (sec)



Average L2norm Length of traj. KK_1 and KK_2 varied while lag = 0.44 (sec)



MIAMI UNIVERSITY OXFORD OHIO

Discussion

- L2 –Norm is useable metric for balance.
- Parametric studies show definite trends and sensitivities.
- Model choice dictates predictive capability as the strategy of balance can change with age.

Many more results in MS Thesis by Carson Willey (see Ohio Link)

OhioLINK ETD Center

The Nonlinear Dynamics of Quiet Standing in Humans

Willey, Carson Landis

MIAMI UNIVERSITY
OXFORD OHIO

Future Work

- Correlation with clinical/experimental data.
- Inclusion of normal forms into the parametric variations for balance.