AN INVERTED PENDULUM MODEL INDICATES THAT PARKINSON'S DISEASE RESULTS IN ALTERED NEUROMUSCULAR STIFFNESS FOR CONTROLLING GAIT

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INTRODUCTION

Inverted pendulums have been used to model locomotion [1,2]. Furthermore, the organization of the dynamic resources available in the neuromuscular system determines the behavior of the inverted pendulum system. These resources can be categorized as the ability of the muscles to produce functional joint torques, passive and active characteristics of the muscles and tendons, and the exchange of potential and kinetic energy [1,2]. An escapement-driven inverted pendulum model has been used successfully to explain how pathological populations (i.e. Cerebral Palsy) utilize these dynamic resources (Figure 1) [1,2].

Parkinson's disease (PD) is a disorder of the basal ganglia that results in a loss of normal motor function [3]. PD patients have irregular stepping patterns and altered lower limb coordination [3]. These movement deficiencies may be related to the inability of PD patients to effectively utilize the available dynamic resources for functional gait. Here we use an escapement-driven inverted pendulum model to reveal how PD patients use the stiffness and dampening resources to control gait.

METHODS

Three-dimensional kinematics of the lower extremity were collected as five subjects with idiopathic PD (Age = 64 $\pm$ 7.0 yrs) and five healthy controls (66 $\pm$ 7.7 yrs) walked on a treadmill at the self-selected pace. All PD subjects were off dopamine treatment and had a Unified PD Rating Scale in the 53rd percentile. Equation 1 represents the dynamics of the escapement-driven inverted pendulum model used in this investigation (Figure 1).

$$ML^2\ddot{\theta} = FL + MLg\theta - kb^2\theta - cb\dot{\theta} \qquad \text{Equation 1.}$$

where M is the mass of the body, θ is leg angle, L is the distance from the axis of rotation to the center of mass of the physical pendulum, F is the active muscle force from the opposite leg, k is the stiffness, b is the distance of the spring from the axis of rotation, g is gravity, c is the dampening, and $\dot{\theta}$ and $\ddot{\theta}$ represent the angular derivatives of the inverted pendulum. Anthropometric measurements were utilized to fit subject's physical characteristics to the model [1,2]. The period of the leg pendulum was computed under the assumption that the time from the start of the stance phase to maxium angular displacement of the leg pendulum represented half of the natural period (τ). The stiffness and dampening of the model was calculated from Equation 2 and 3 respectively [1,2].

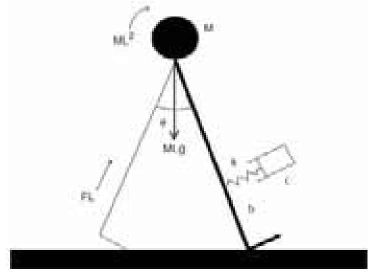

Figure 1. The escapement-driven inverted pendulum model.

$$kb^2 = \frac{ML^2}{(\tau\ /2\pi)^2} + MLg \qquad \text{Equation 2.}$$

$$cb^2 = 2 * \sqrt{ML^2\ (kb^2 - MLg)} \qquad \text{Equation 3.}$$

The stiffness and dampening values were normalized by the subject's walking speed and MLg in order to control for differences in walking speeds and anthropometrics between the two groups [1,2].

RESULTS AND DISCUSSION

PD subjects had significantly less stiffness during locomotion (Table 1). Stiffness in the model is a result of the elastic tissues and active muscular tension [1,2]. The altered stiffness may be related to the impaired reflexes and muscular activation found in PD patients [3]. Stiffness deficiencies may be related to the irregular stepping patterns and higher incidence of falls found in PD patients [3]. Future investigations will investigate if dopamine therapy restores the use of effective dynamic resource strategies in PD patients.

REFERENCES

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Table 1. Means and standard deviations of stiffness and dampening values. * significant differences between groups at $p < 0.05$.

Group	Stiffness	Dampening
PD	7.78 (3.7)*	1.95 (.84)
Control	12.08 (1.6)	2.09 (.56)