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# Early biomechanical markers of postural instability in Parkinson's disease

Molly A. McVey [a], Antonis P. Stylianou [a,b], Carl W. Luchies [a,b,*], Kelly E. Lyons [b], Rajesh Pahwa [b], Stephen Jernigan [b], Jonathan D. Mahnken [b]

[a] The University of Kansas, 1530 West 15th St, Rm 3138, Lawrence, KS 66045-7609, United States
[b] The University of Kansas Medical Center, 3901 Rainbow Blvd., Kansas City, KS 66160, United States

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ABSTRACT

Current clinical assessments do not adequately detect the onset of postural instability in the early stages of Parkinson's disease (PD). The aim of this study was to identify biomechanical variables that are sensitive to the effects of early Parkinson's disease on the ability to recovery from a balance disturbance. Ten adults diagnosed with idiopathic PD and no clinically detectable postural instability, and ten healthy age-range matched controls (HC) completed the study. The first step in the response to a backwards waist pull was quantified in terms of strategy, temporal, kinematic, kinetic, and center of pressure (COP) variables. People with PD, compared to HC, tended to be less consistent in the choice of stepping limb, utilized more time for weight shift, used a modified ankle joint motion prior to liftoff, and the COP was further posterior at landing. The study results demonstrate that PD changes the response to a balance disturbance which can be quantified using biomechanical variables even before the presence of clinically detectable postural instability. Further studies are required to determine if these variables are sensitive and specific to postural instability.



## 1. Introduction

Postural instability is one of the most disabling symptoms of Parkinson's disease (PD) and one factor that increases the risk of falling, which occurs in up to 68% of people with PD [1,2]. Falls can have devastating effects on quality of life including fractures, hospitalization, loss of independence, and restriction of activities [3–6]. Interventions to reduce fall risk are likely most effective if they are implemented before someone falls, but current clinical assessments are not sensitive enough to detect postural instability prior to a fall [7–9]. Laboratory-based experiments are the necessary first steps toward developing more effective clinical measures of postural instability. Laboratory measurements of a balance recovery task may be more sensitive to postural instability earlier in the progression of Parkinson's disease, as has been recently demonstrated with postural sway [10,11].

Balance recovery variables, based on the biomechanical analysis of the step response to a balance disturbance, may effectively detect early signs of postural instability. The biomechanics of this step response have been widely studied to determine the effects of aging. Compared to young adults, older adults use a stepping strategy at smaller disturbances, take multiple, shorter steps, and step more laterally in response to an anterior or posterior perturbation [12–14]. They also generate larger peak ankle and hip torque and power [15–17], and show reduced hip flexion, knee flexion and extension, and ankle plantarflexion velocity [18]. Older adults with balance impairments, compared to those without balance impairments, use less ankle dorsiflexion and knee flexion prior to step liftoff, take more steps, and step more laterally in response to a backwards pull [12].

Previous studies of postural instability in people with PD have primarily focused on patients who already exhibit balance deficits and postural instability [19–23]. Jacobs and Horak demonstrated that people with moderate and severe PD, compared to healthy controls, utilized shorter steps [22], multiple anticipatory postural adjustments, and were less consistent in the choice of stepping limb in response to a backwards surface translation [24]. The authors suggested that this altered response may demonstrate an inability to quickly select an appropriate response, which has also been observed in young adults when they are unable to pre-select their stepping foot [25]. The step response to a balance perturbation prior to the presence of clinically recognized postural instability has not been studied.

The primary aim of this pilot study was to identify balance recovery variables that may be sensitive to the differences between people with PD but without clinically diagnosed postural instability, and healthy controls. Further studies are required to

* Corresponding author at: The University of Kansas, 1530 West 15th St, Rm 3138, Lawrence, KS 66045-7609, United States. Tel.: +1 785 864 2993; fax: +1 785 864 5254.
*E-mail address:* luchies@ku.edu (C.W. Luchies).

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determine if these variables are sensitive and specific to postural instability.

## 2. Methods

### 2.1. Participants

Ten adults diagnosed with idiopathic PD (PD: age 63 (48–77) years, height: 167 (158–176) cm, mass: 76 (55–94) kg) and 10 healthy age-range matched controls (HC: age 67 (48–79) years, height: 165 (150–188) cm, mass: 69 (55–91) kg) completed the study (5 males and 5 females in each group). Exclusion criteria included dementia (MMSE $< 24$) [26], significant depression (BDI $> 14$) [27] and inability to ambulate without assistance. All participants gave written informed consent approved by the institution's Institutional Review Board (approval number 10330).

HC living independently were recruited from existing databases and the community. Medical history and a physical examination excluded those with cardiovascular, musculoskeletal and neurological impairments. People diagnosed with idiopathic PD were recruited from the institution's PD Center and were assessed with the Unified Parkinson's Disease Rating Scale (UPDRS). Exclusion criteria included postural instability (H&Y $> 2$), deep brain stimulators, or a history of significant musculoskeletal, neurological, or cognitive impairments other than those associated with PD. The participants with PD were instructed to maintain their regular medication schedule (Table 1) and were tested during the medication "on" phase, which was $2.08 \pm 0.87$ h after the administration of medications.

### 2.2. Task

The participant stood with arms crossed at the chest. For safety purposes, a harness connected to an overhead support was worn by the participant and a research assistant stood nearby to help prevent injury in case of a fall. The participant wore an adjustable but rigid waist harness that was connected to a weight-drop mechanism via a cable in the back of the harness. When triggered, the weight-drop mechanism produced a posterior waist pull by dropping a weight (20% body weight) with a pull distance equal to 8.7% of waist height [14]. The pull magnitude was large enough to ensure that each participant used a step response to recover balance. The participant was instructed to respond naturally to the posterior pull, which was repeated until three good trials were obtained. Examples of bad trials included not stepping onto a force plate or obstructing the cameras' view of kinematic markers. A maximum of six trials were performed by each participant.

### 2.3. Experimental measurements

Video, motion, and analog data (force plate, EMG, and load cell) were collected for each trial. Reflective markers, sampled at 120 Hz using a Vicon 512 (Vicon Peak, Lake Forest, CA) six camera system, were placed bilaterally on the 2nd metatarsal, lateral malleolus, heel, calf, and lateral femoral condyle. Bilateral tibialis anterior (TA) EMG activity was measured using a Noraxon telemetry surface electrode system (Noraxon, Scottsdale, AZ). Ground force reactions were measured using three AMTI force plates (Advanced Mechanical Technology Inc., Watertown, MA). The tensile force in the cable attached to the waist harness was measured using a biaxial custom-built load cell. Analog data were sampled at 1080 Hz using a 16-bit A/D data acquisition system controlled with the Vicon workstation.

### 2.4. Data analysis

Motion data were filtered with a Woltring filtering routine (MSE = 20) in the Vicon software. EMG data were full wave rectified and filtered using a second order low pass Butterworth filter (cutoff frequency = 50 Hz). Force plate and load cell data were similarly filtered (cutoff frequency = 20 Hz). Initial and final-time artifacts were minimized using forward and backward reflection of the data [28], and phase shift was eliminated by using forward and backward passes [29]. Data from all trials were processed using MATLAB (Mathworks, Natick, MA).

### 2.5. Strategy variables

The number of steps taken, a single vs. multiple step response, and consistency in the foot used for each initial step were determined. A multiple step response was defined as using more

**Table 1**
Characteristics of Parkinson's Disease Group.

| Subject no. | Age (years) | Sex | UPDRS total | UPDRS motor | UPDRS #33 | H&Y | Duration (years) | Medication | Dosage (mg/day) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 77 | M | 37 | 27 | 1 | 2 | 1 | Carbidopa/Levodopa | 150/600 |
| 2 | 62 | M | 34 | 25 | 0 | 2 | 5 | Carbidopa/Levodopa/Entacapone<br>Trihexyphenidyl | 150/600/800<br>4 |
| 3 | 65 | F | 10 | 9 | 0 | 2 | 4 | Carbidopa/Levodopa/Entacapone<br>Ropinirole | 150/600/800<br>9 |
| 4 | 64 | M | 33 | 24 | 0 | 2 | 13 | Carbidopa/Levodopa/Entacapone<br>Carbidopa/Levodopa<br>Pramiprexole | 225/900/1200<br>100/400<br>0.75 |
| 5 | 73 | F | 22 | 17 | 1 | 2 | 3 | Carbidopa/Levodopa | 75/300 |
| 6 | 51 | M | 30 | 24 | 0 | 2 | 2 | Carbidopa/Levodopa | 150/600 |
| 7 | 48 | F | 11 | 9 | 0 | 2 | 2 | Rasagiline | 1 |
| 8 | 69 | M | 60 | 38 | 0 | 2 | 5 | Carbidopa/Levodopa | 100/400 |
| 9 | 63 | F | 18 | 14 | 0 | 2 | 12<br>‘ | Carbidopa/Levodopa<br>Carbidopa/Levodopa CR<br>Entacapone<br>Pramiprexole | 100/400<br>200/800<br>800<br>3 |
| 10 | 60 | F | 18 | 14 | 0 | 2 | 1 | Carbidopa/Levodopa | 75/300 |
| AVG | 63.2 | | 27.3 | 20.1 | 0.2 | 2.0 | 4.8 | | |
| STD | 8.9 | | 15.0 | 9.1 | 0.4 | 0.0 | 4.3 | | |