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Impaired synergic control of posture in Parkinson's patients without postural instability

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ABSTRACT

Background: Postural instability is one of most disabling motor symptoms in Parkinson's disease. Indices of multi-muscle synergies are new measurements of movement and postural stability.
Objectives: Multi-muscle synergies stabilizing vertical posture were studied in Parkinson's disease patients without clinical symptoms of postural instability (Hoehn-Yahr $\leq$ II) and age-matched controls. We tested the hypothesis that both synergy indices during quiet standing and synergy adjustments to self-triggered postural perturbations would be reduced in patients.
Methods: Eleven Parkinson's disease patients and 11 controls performed whole-body tasks while standing. Surface electromyography was used to quantify synergy indices stabilizing center of pressure shifts in the anterior–posterior direction during a load-release task.
Results: Parkinson's disease patients showed a significantly lower percentage of variance in the muscle activation space accounted for by the first four principal components, significantly reduced synergy indices during steady state, and significantly reduced anticipatory synergy adjustments (a drop in the synergy index prior to the self-triggered unloading).
Conclusions: The study demonstrates for the first time that impaired synergic control in Parkinson's disease can be quantified in postural tasks, even in patients without clinical manifestations of postural instability. Synergy measurements may provide a biomarker sensitive for early problems with postural stability in Parkinson's disease.

1. Introduction

Parkinson's disease (PD) is diagnosed clinically by the presence of rest tremor, rigidity, and bradykinesia. Postural instability and associated symptoms, such as episodes of freezing, emerge as the disease progresses and represent the most disabling symptoms of PD [1]. The presence of postural instability is a clinically important landmark in PD, signifying the transition from Hoehn-Yahr (HY, [2]) stage-II to stage-III. During typical clinical evaluations, postural instability is assessed using qualitative tests such as the pull test [3,4]. Whereas limitations of posturography in clinical studies have been emphasized recently [5], consistent changes in postural sway, postural adjustments prior to stepping, and responses to perturbations have been reported in stage-III PD [6–9].

The concept of motor synergy has evolved over the past 20 years (reviewed in refs. [10,11]). Synergy is defined as a neural organization of a large set of effectors providing the stability of important performance variables [10]. For example, during multi-digit prehension, individual digit forces and moments co-vary to stabilize the resultant force/moment acting on the grasped object [12]. A synergy index has been introduced reflecting the relative amount of across-trials variance that does not affect a salient performance variable [10]. During steady-state actions, the synergy index typically is high. When a person is preparing for a quick action from a steady state, the synergy index drops 200–300 ms prior to action initiation. These anticipatory synergy adjustments (ASAs [13,14]) represent an important reflection of

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controlled stability that allows combining stability during steady state and agility in transition to a quick action [15].

Recent studies in PD patients have suggested that indices of motor synergies may be used as sensitive biomarkers of PD even in extremities that show no clinically identifiable motor symptoms [16–18]. In particular, patients at HY stage-I (with clinical signs limited to one side of the body) showed comparably impaired indices of multi-finger synergies and impaired ASAs in both the symptomatic and asymptomatic hands [16].

In the current study, we explored whether indices of multi-muscle synergies stabilizing the coordinate of the center of pressure (COP) are able to detect postural stability changes in PD patients at ≤HY stage-II without clinically identifiable postural instability. Our main hypothesis had two parts. First, during steady state (quiet standing) we expected lower synergy indices in PD patients compared to age-matched controls. Second, we expected significantly smaller ASAs in PD patients during preparation to a self-triggered postural perturbation.

2. Methods

2.1. Subjects

A group of 11 right-handed (6 females) PD patients without clinical postural instability (HY stage ≤II, aged 69.4 ± 6.3 years, mean ± standard deviation, SD) and 11 (5 females) healthy controls (aged 65.3 ± 8.1 years) participated in this study. Clinical postural stability was defined as lack of falls and negative on pull back test as part of Unified PD rating scale-part III. Detailed demographic and clinical information is presented in Table 1. All PD participants were tested on their prescribed medications. Written informed consent was obtained from all participants according to the protocol approved by the Penn State Hershey Institutional Review Board.

2.2. Apparatus

Subjects were tested while standing on a force platform (AMTI, OPTIMA). The platform recorded the horizontal component of the reaction force in the anterior–posterior direction (F_X) as well as its vertical component (F_Z), and the moment of force about a horizontal axis in the frontal plane (M_Y). A 23″ monitor mounted at eye level 1.5 m from the subject was used for visual feedback.

A 16-channel Trigno Wireless System (Delsys) was used to record the surface muscle activity (electromyogram, EMG). Active electrodes were placed over the bellies of the following right side muscles: tibialis anterior (TA), soleus (SOL), gastrocnemius medialis (GM), gastrocnemius lateralis (GL), biceps femoris (BF), semitendinosus (ST), rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), tensor fasciae latae (TFL), lumbar erector spinae (ESL), thoracic erector spinae (EST), and rectus abdominis (RA). EMG signals were pre-amplified and band-pass filtered (20–450 Hz) before being transmitted to the base station connected to a data collection computer (Dell, Xeon 2 GHz). EMG and force platform data were sampled at 1 kHz with 12-bit resolution (PCI-6225, National Instruments) using customized LabVIEW-based software (LabVIEW 2013).

2.3. Procedures

To ensure participant safety, all subjects used a safety harness. Initially, subjects were asked to stand on the force plate while keeping their feet parallel at shoulder width; the foot position was marked and reproduced across trials. The experiment started with a 30-s quiet standing trial used to record baseline EMG signals. The main experiment consisted of three tasks: voluntary sway (VS), fast-sway (FS), and load release (LR). Prior to each task, subjects performed a few familiarization trials.

Table 1
Description of the participants.

PD group						
Patient	Gender, M/F	Age (years)	Symptom Onset, R/L	Years since diagnosis	UPDRS motor score	Total LEDD (mg)
1	F	72	R	3.5	11	300
2	F	73	L	4.5	18	480
3	F	72	L	4	38	300
4	F	70	Bilateral	0.8	13	500
5	M	72	R	4.6	15	167
6	M	69	Bilateral	1.6	8	195
7	M	79	R	2.2	8	500
8	M	67	L	7.6	5	737.5
9	M	71	R	3.1	21	400
10	F	55	R	2.2	2	250
11	F	63	R	4.7	18	700
Mean	F (6)	67.5 ± 7.4				
Mean	M (5)	71.6 ± 4.6				

CO group		
Control	Gender, M/F	Age (years)
1	M	56
2	F	58
3	F	67
4	F	54
5	M	77
6	M	78
7	M	69
8	F	71
9	M	64
10	M	63
11	F	61
Mean	F (5)	62.1 ± 7.1
Mean	M (6)	68.0 ± 8.4

M/F, male/females; R/L, right/left; LEDD, levodopa equivalent daily dose; UPDRS, Unified Parkinson's Disease Rating Scale.