Sensorimotor transformations for balance in Parkinson’s disease are temporally precise but spatially diffuse

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Abstract

Motivation
Parkinson’s disease (PD) causes balance problems and falls, but we know very little about how it affects balance pathways.

Muscles activate in proportion to CoM motion when balance is disturbed in animals and healthy young people.1,2 Muscle activity begins ~100 ms after perturbation onset to stabilize the CoM independent of perturbations to individual joints.3 This reactive balance activity depends on brainstem and spinal networks, with important roles for subcortical structures including thalamus and subthalamic nucleus (STN).4,5

We characterize the transfer from CoM perturbation to muscle activity using our sensorimotor response model (SRM). Muscle activity is characterized by feedback gains on CoM acceleration, velocity and displacement (λh, λv, and sensory-neuroconduction delay (τ)).

Objectives
Here, we tested whether:
1) The sensorimotor transformation governing reactive balance is disrupted in PD patients compared to matched neurotypical individuals.
2) Abnormalities in the balance sensorimotor transformation are associated with previous and future falls in PD patients.

Methods
Participants and setting
N=44 PD / N=23 non-PD participants.

Reactive balance testing

Sensorimotor Feedback Scenarios

Stabilizing CoM Feedback

Motion capture
Safety harness
Surface EMG
Force Plates
Perturbation platform

Ramp-and-heel support surface translation perturbations
- 30 cm, delivered in reproducible step sequentially among 10 directions evenly distributed in the horizontal plane
- Perturbation duration: 0.1 s, peak velocity: 20 cm/s, peak displacement: 7.0 cm
- Perturbations within 20° of anterior-posterior were entered into analyses using anterior-posterior components of CoM motion

Sensorimotor Response Modeling

SRM was performed. The time course of muscle activity were found by minimizing an error term calculated between experiment and reconstruction:

Identified delay times

Case Study

3) Abnormal sensorimotor control can precede first falls in de novo PD.

Discussion – Case Study

This case provides compelling evidence that SRM analysis can identify those at risk for “first falls” in time to direct them to appropriate interventions. It also provides evidence that postural abnormalities associated with falls identified with SRM analysis precede — rather than result from, as a compensatory strategy — balance impairments. Clinical tests derived from SRM analysis could therefore potentially identify fall-prone PD patients for interventions.1,2

Abbreviations

References

Support
NII K25 HD086276
R01 HD046922

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Results
Sensorimotor control of the CoM: 1) is abnormal in mild-moderate PD, and, 2) is associated with falls

N=44 PD and N=16 non-PD participants included in SRM analyses in the balance sensorimotor transformation.

In summary, evidence suggests that SRM abnormalities identified in PD patients, in concert with clinical findings, are associated with postural abnormalities that precede falls. This provides a potential framework to identify individuals with PD at increased risk for falls and to prioritize effective therapeutic interventions.

Discussion

Sensorimotor transformations for balance in Parkinson’s disease are temporally precise but spatially diffuse.