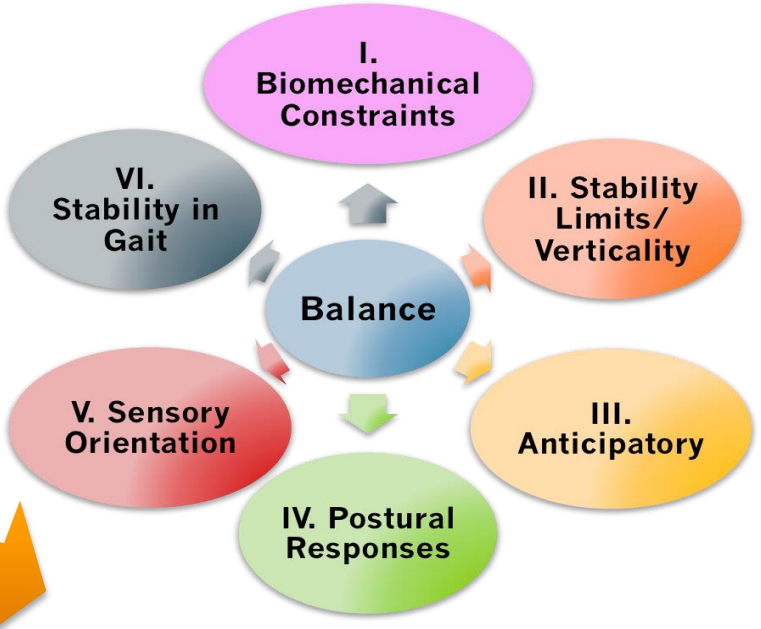
Fay B. Horak PhD, PT
Professor of Neurology
Portland VA and OHSU
Balance Disorders Laboratories

Objective Measures of Balance and Gait for Rehabilitation

Objectives

- **Understand how system impairments underlie balance and gait dysfunction**
- **Discover technology that allows clinicians to measure objective balance and gait impairments**
- **Learn how continuous monitoring of mobility may reveal more impairments**



Body-Worn Sensors:

Mobility Lab

Laboratory:

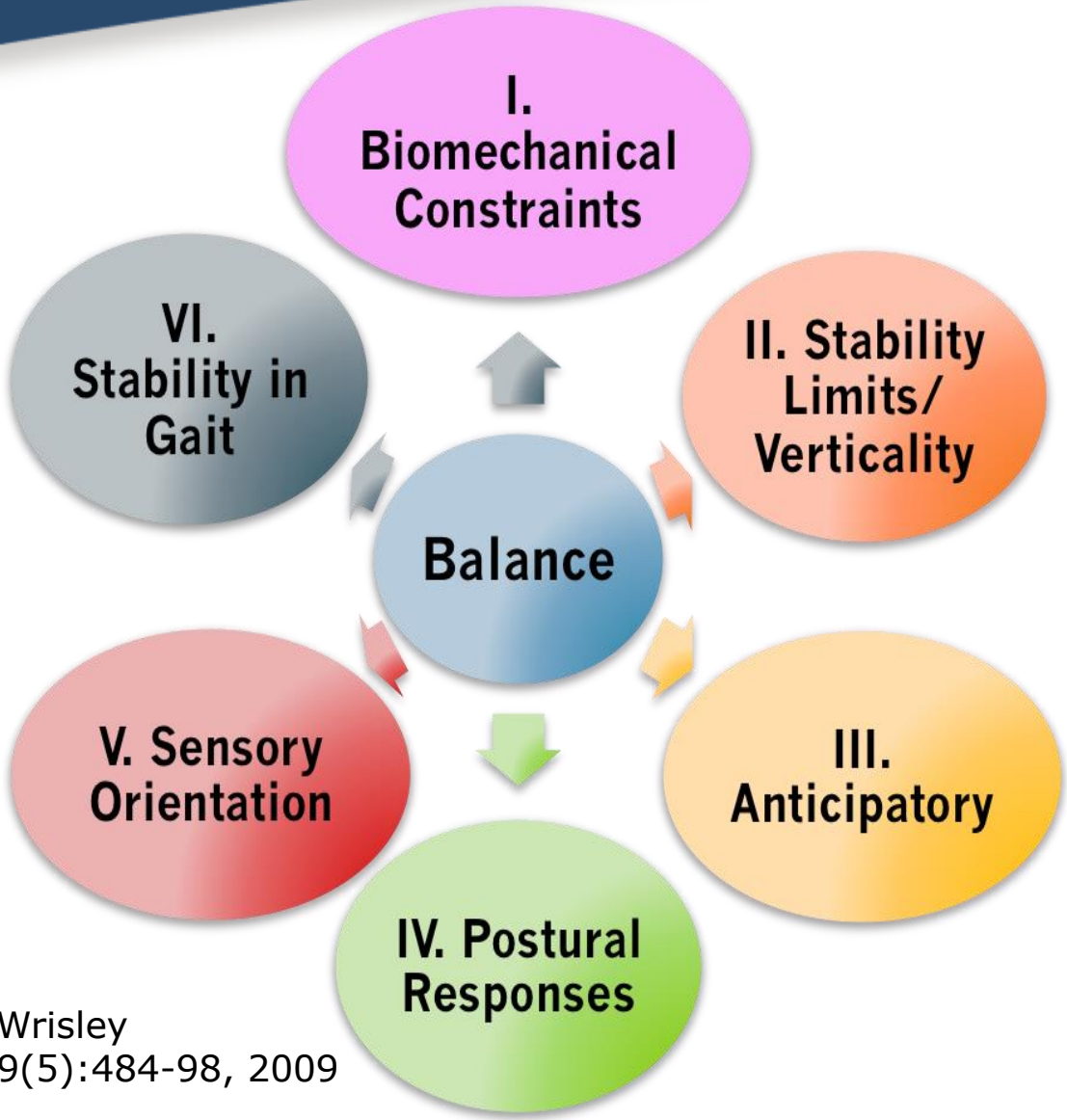
Balance Systems

Clinic:

BESTest

MiniBESTest

Systems Underlying Postural Control



BESTest
Horak, Frank, and Wrisley
Physical Therapy 89(5):484-98, 2009

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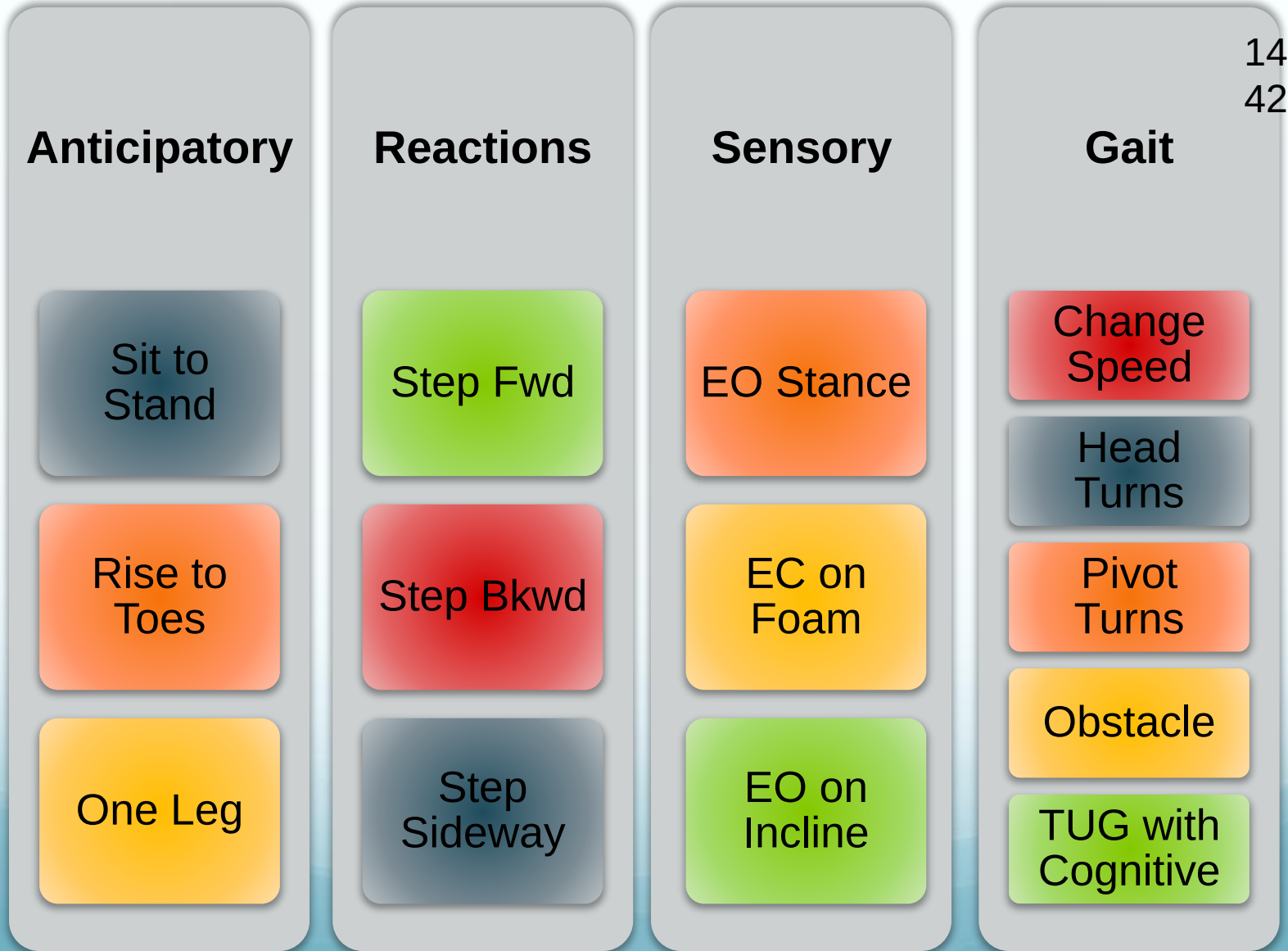
MiniBESTest for Dynamic Balance

Franchignoni, Godi, Nardone, Horak, J Rehab Med 2010

Scores:
2 Normal
1 Abnormal
0 Absent

14 items
42 pt MAX

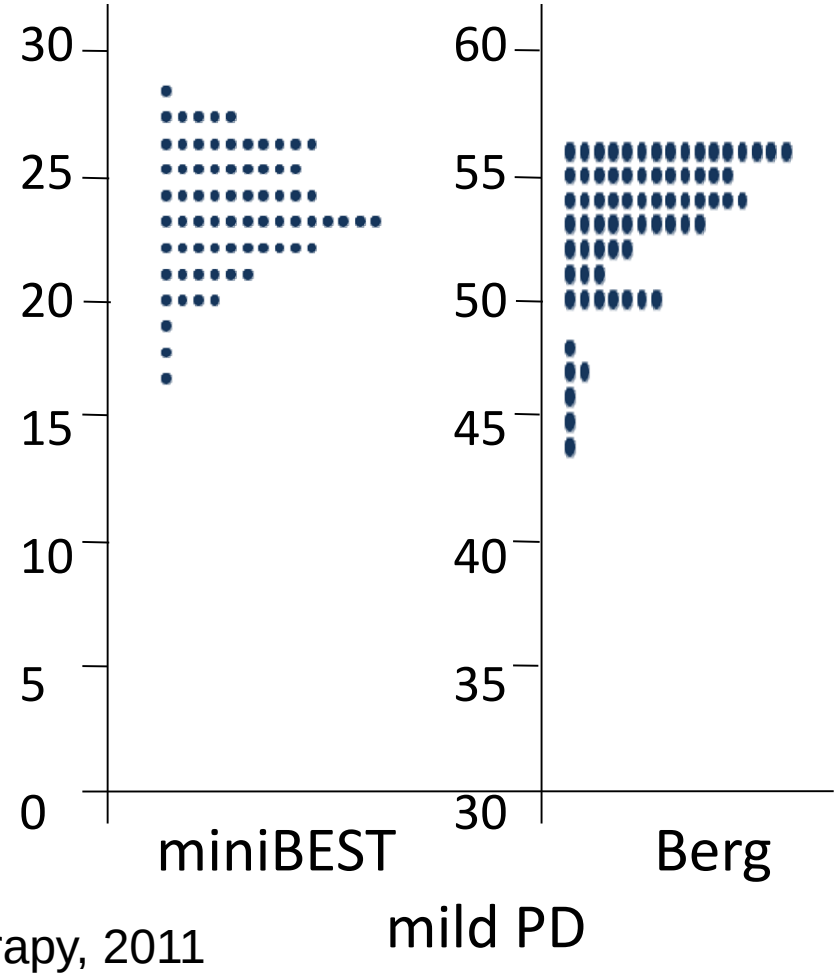


MiniBESTest has great Clinimetrics

4 Systems
- Anticipatory
- Reactive
- Sensory
- Gait

Psycho-metrics
- No Ceiling Effects 2%
- No Redundancy
- Min Detec Change 3.5
- Min Clinical Diff 4

Clinical
- Fast (10 Min)
- Reliable .96
- Fall Risk
- Sensitive to Rehab



Leddy et al J Neurolog Physical Therapy, 2011
Godi et al Phys Therapy 2012
Ryan et al Parkinsons Disease 2012
Sachi et al Thys Therapy 2014
Franchignoni et al, 2015

But NOT Objective!

In a Clinic

OPALS by APDM
APDM.com

Long-Term Monitoring

Synchronized,
wireless sensors

OHSU and Dr. Horak have a significant financial interest in APDM, a company that may have a commercial interest in the results of this research and technology. This potential conflict of interest has been reviewed and managed by OHSU and the Integrity Program Oversight Council.

Body-worn Inertial Sensors:

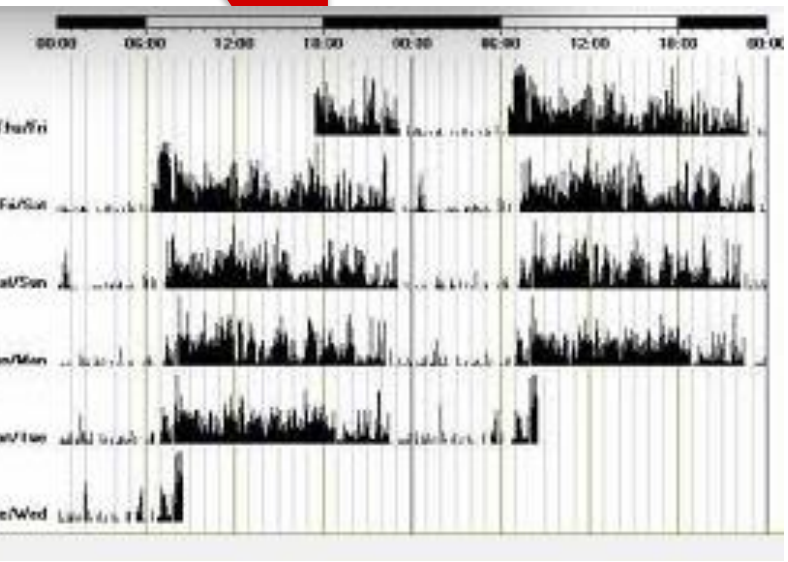
Activity vs Movement Monitors

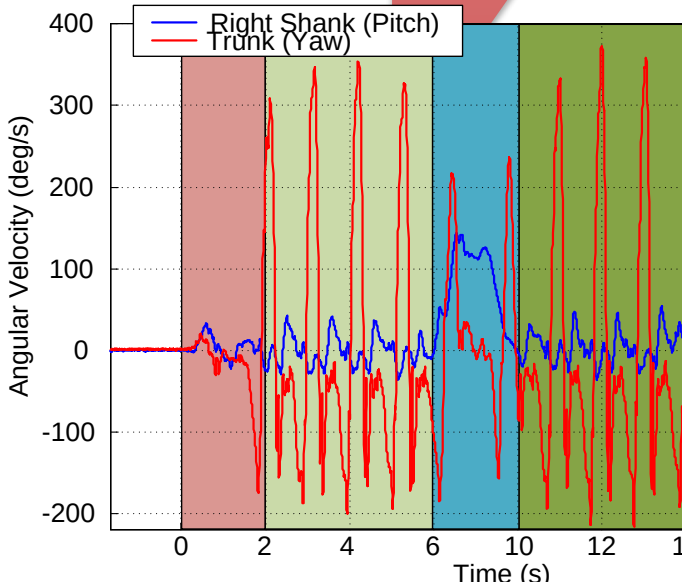
Activity Monitors

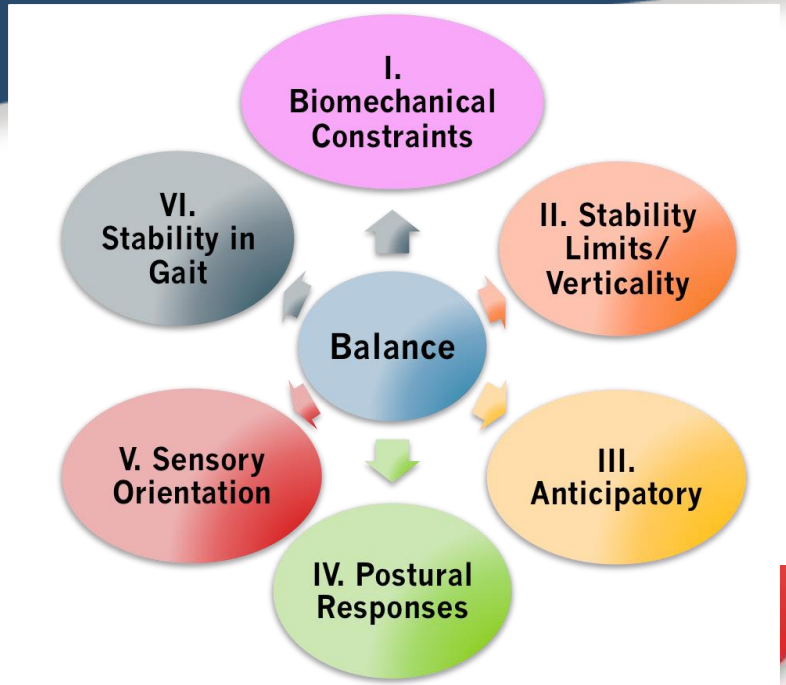
- Accelerometers
- Quantity of Movement - Sedentary or Active
- Pedometer
- Consumer devices

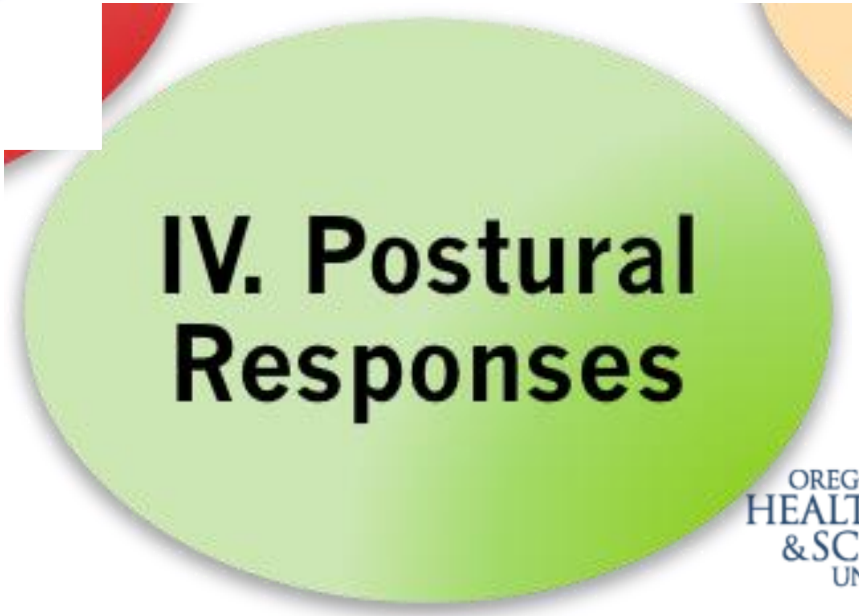
Movement Monitors

- Accelerometers +Gyroscopes + Magnetometer
- Quality of Movement- kinematics
- Impairments
- Medical Devices









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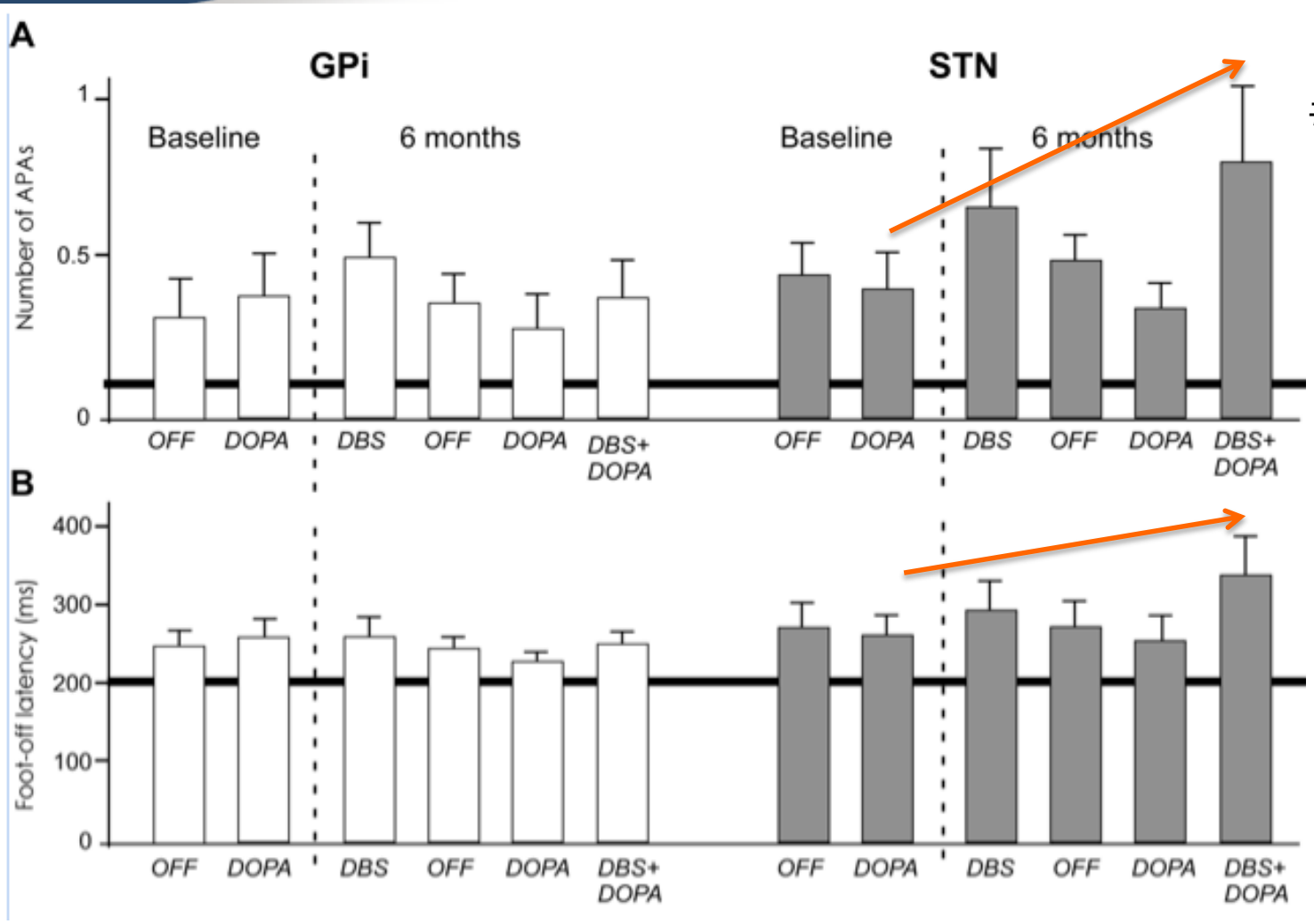
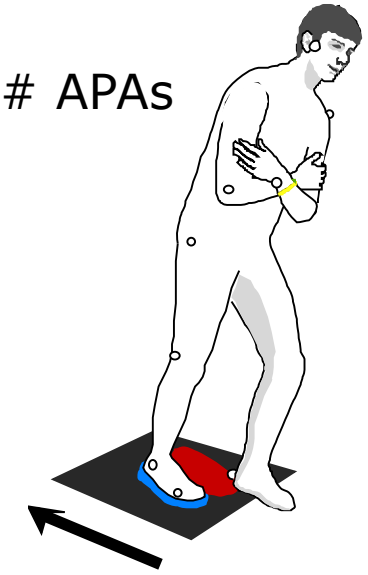
Compensatory Stepping

DBS in STN impairs postural preparation but not compensatory step



APAs



Latency

St George et al, in press

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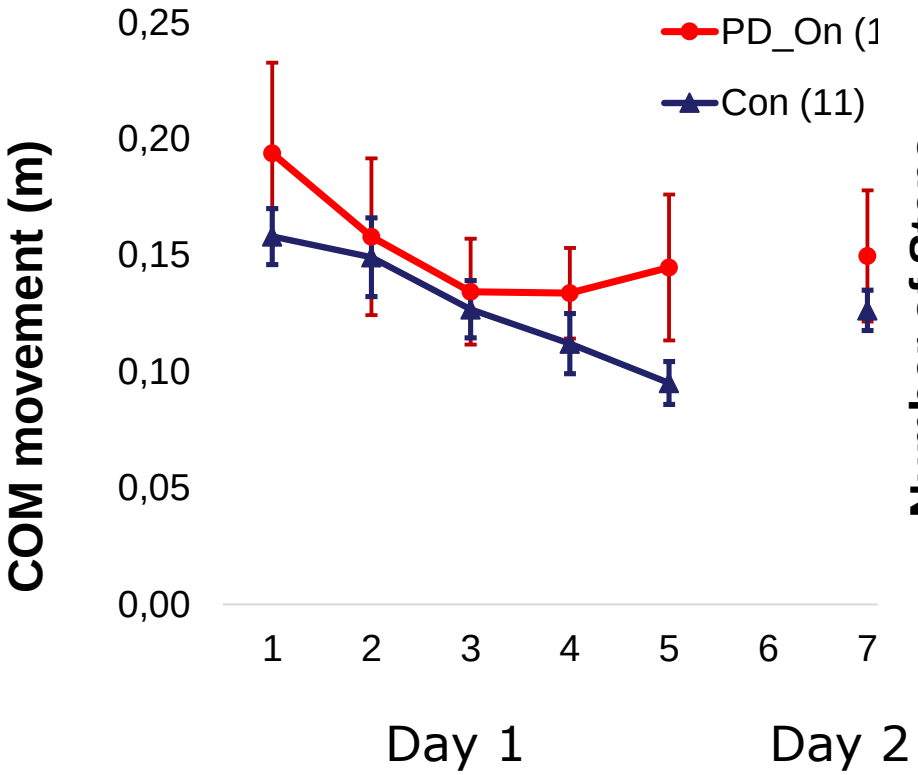
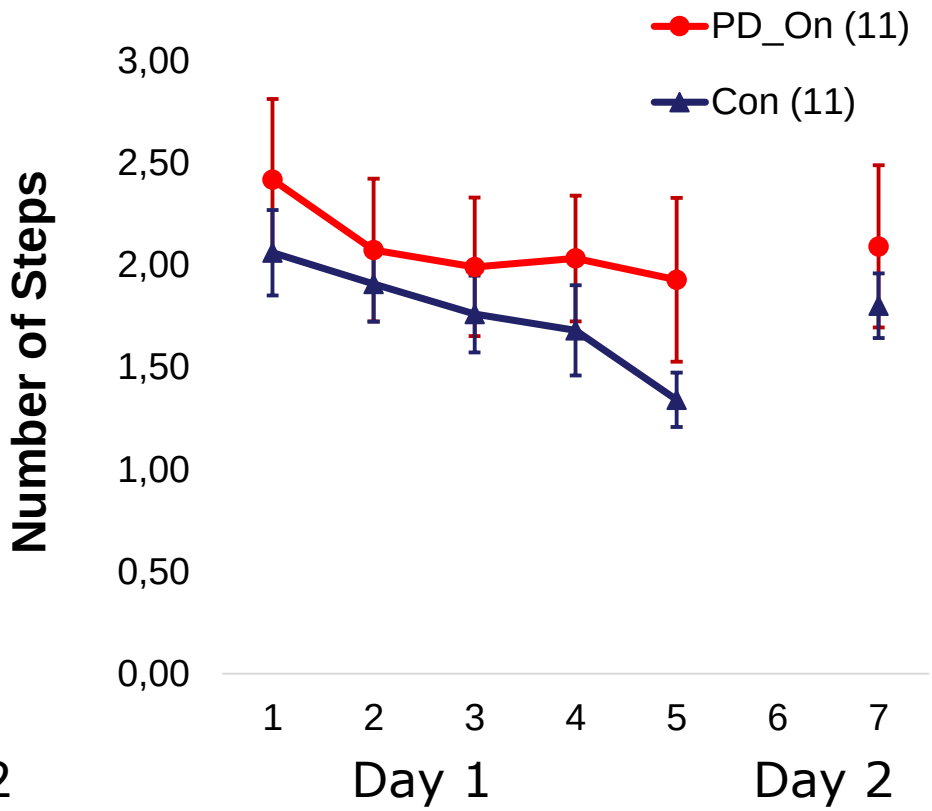
Improvement of stepping responses with practice in elderly control and PD subjects

Peterson and Horak

In preparation





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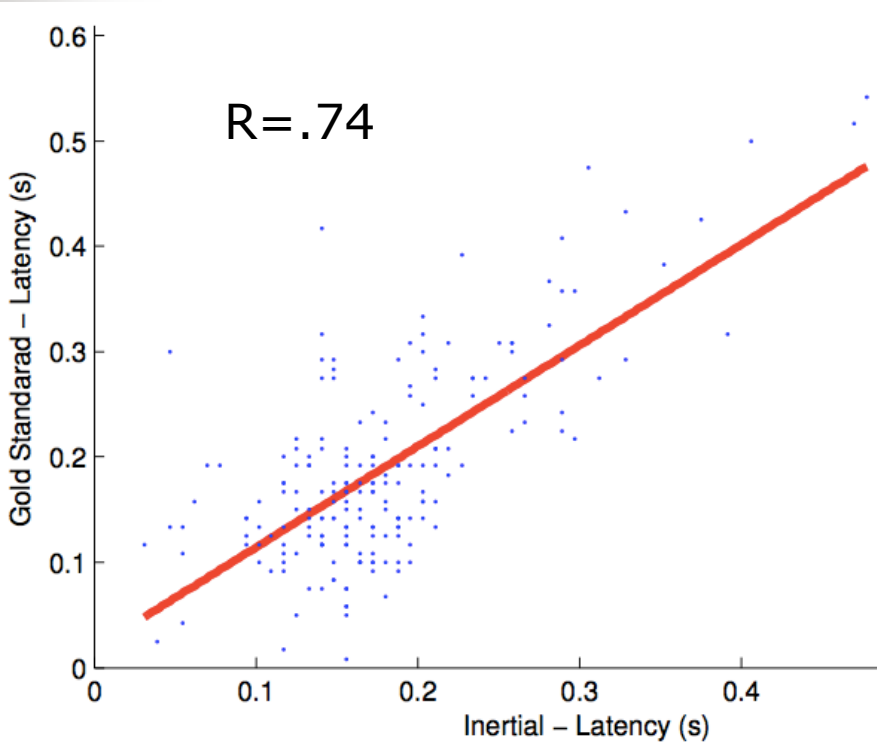
Validating IPush with inertial sensors

El Gohary et al, in prep



N= 50 MS, 50 Controls, 20 PD

Significant difference (p<.01) in:

- Latency (ms):

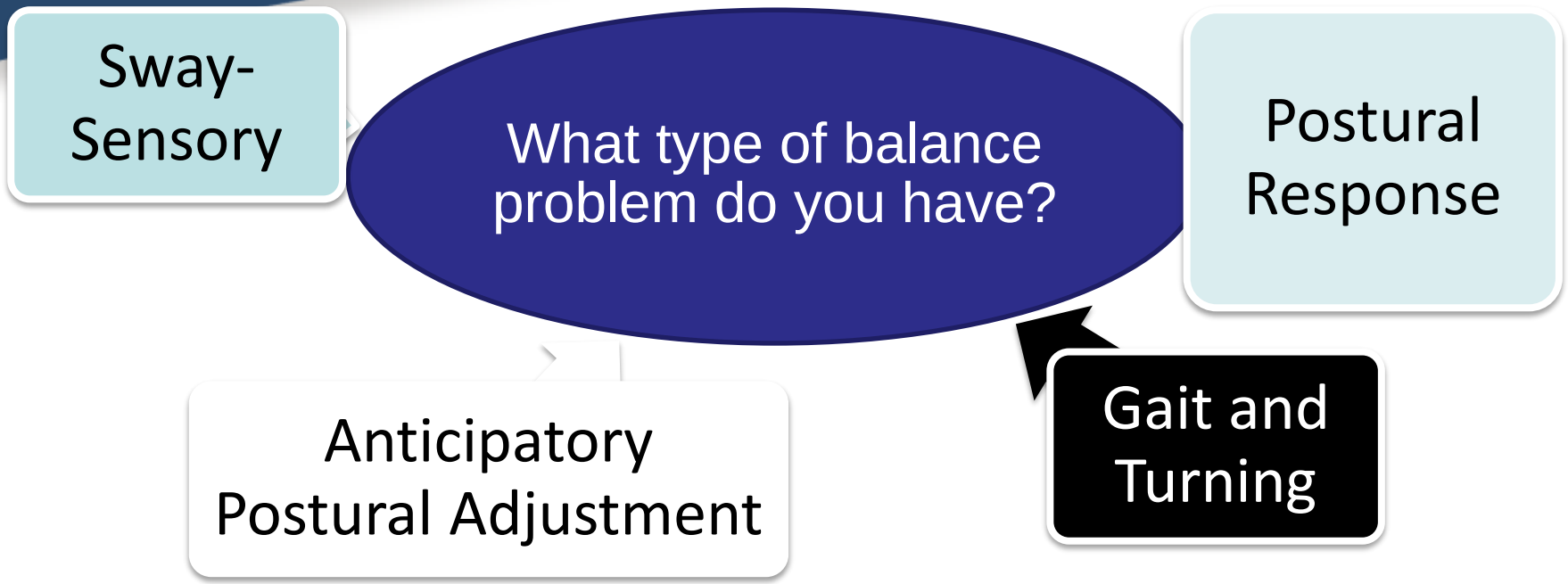
PD = 304, MS = 380, CT = 263

- Step Length (cm):

PD = 32, MS = 48, CT = 45

- Stepping
  - ✓ PD = 3 to 4 small steps
  - ✓ MS = 2 larger steps
  - ✓ CT = one step

Important to test several systems for postural control (quickly)



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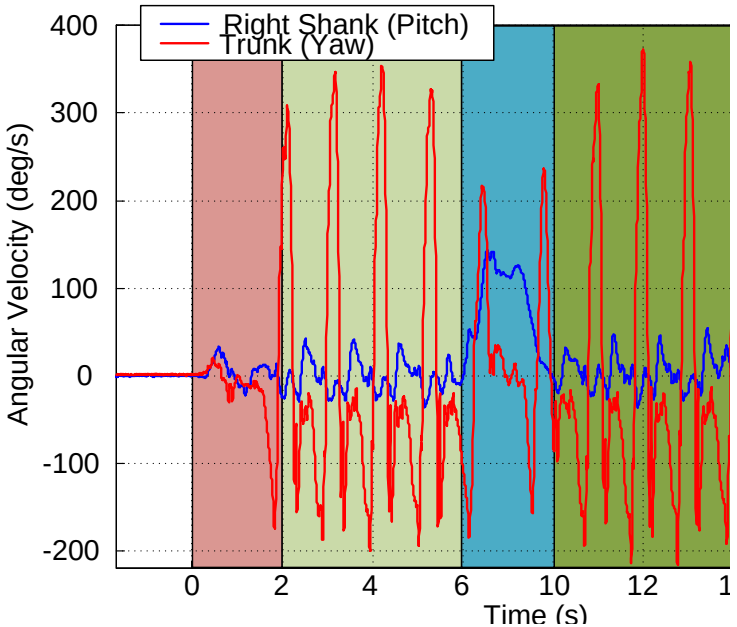
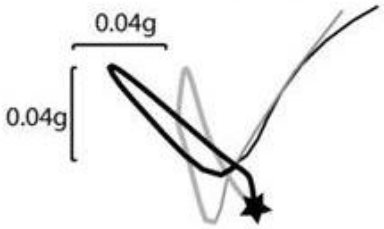
Instrumented Stand and Walk test (ISAW)

Stand + Step Initiation + Walk and turn





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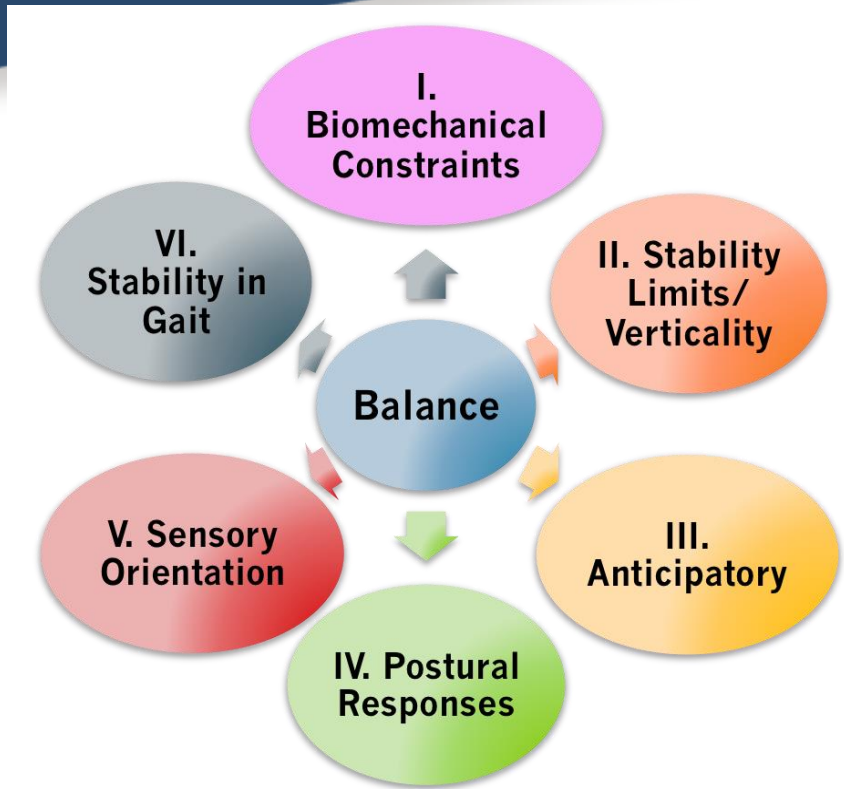
Instrumented Stand and Walk Test (ISAW)



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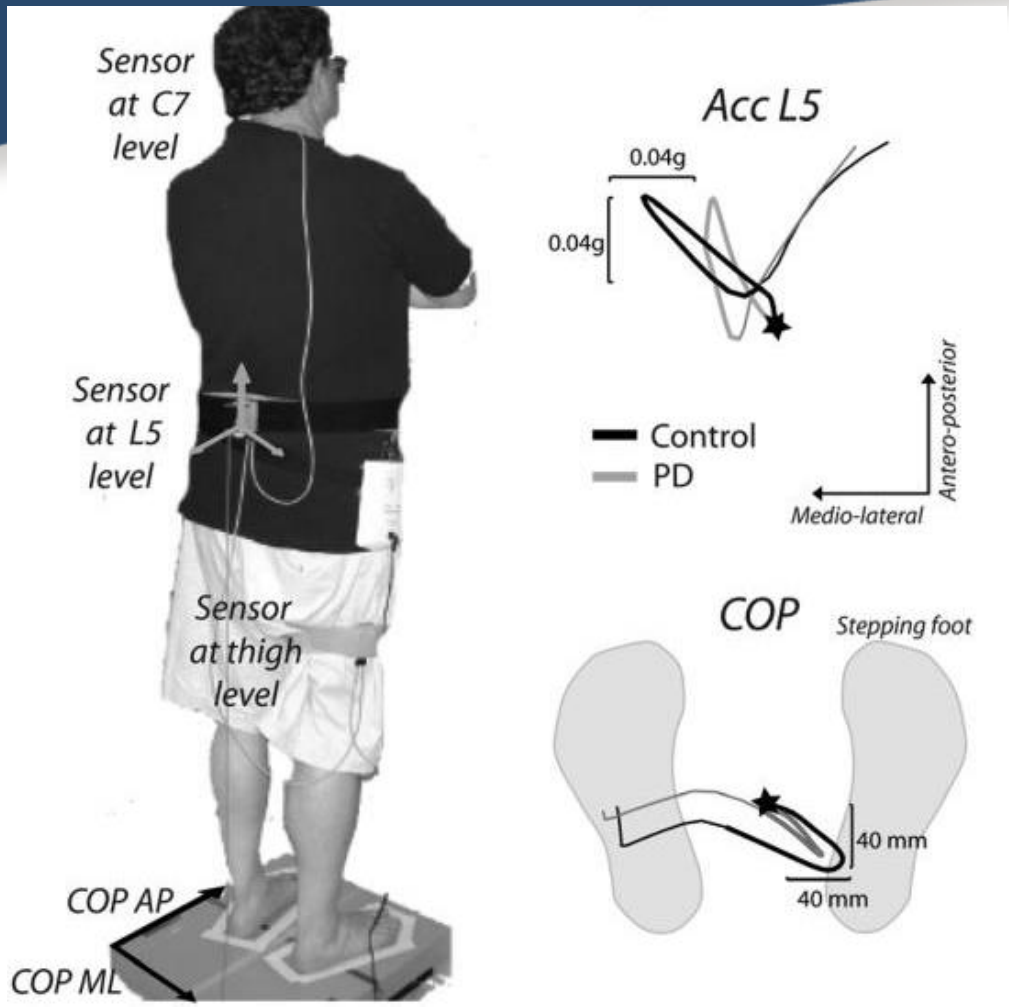
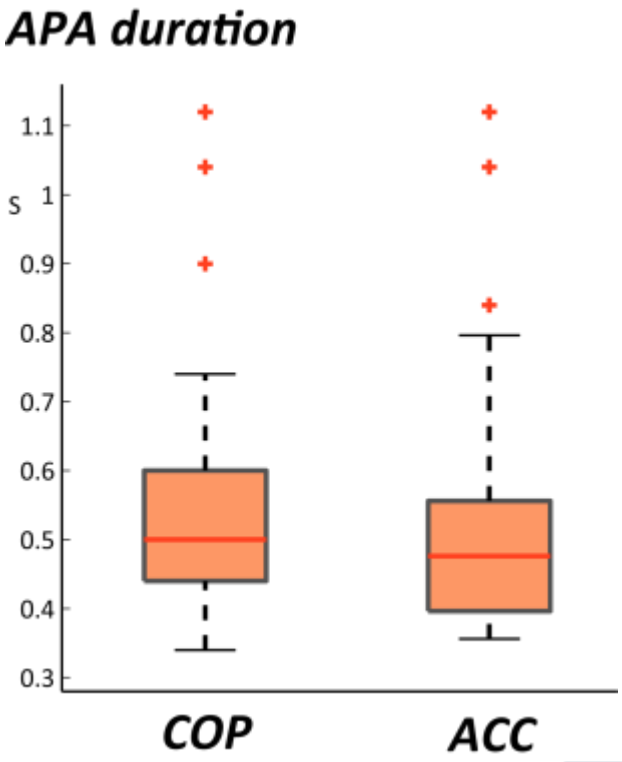
APA with Inertial Sensors: Experimental Validity





Mancini M., et al., 2009

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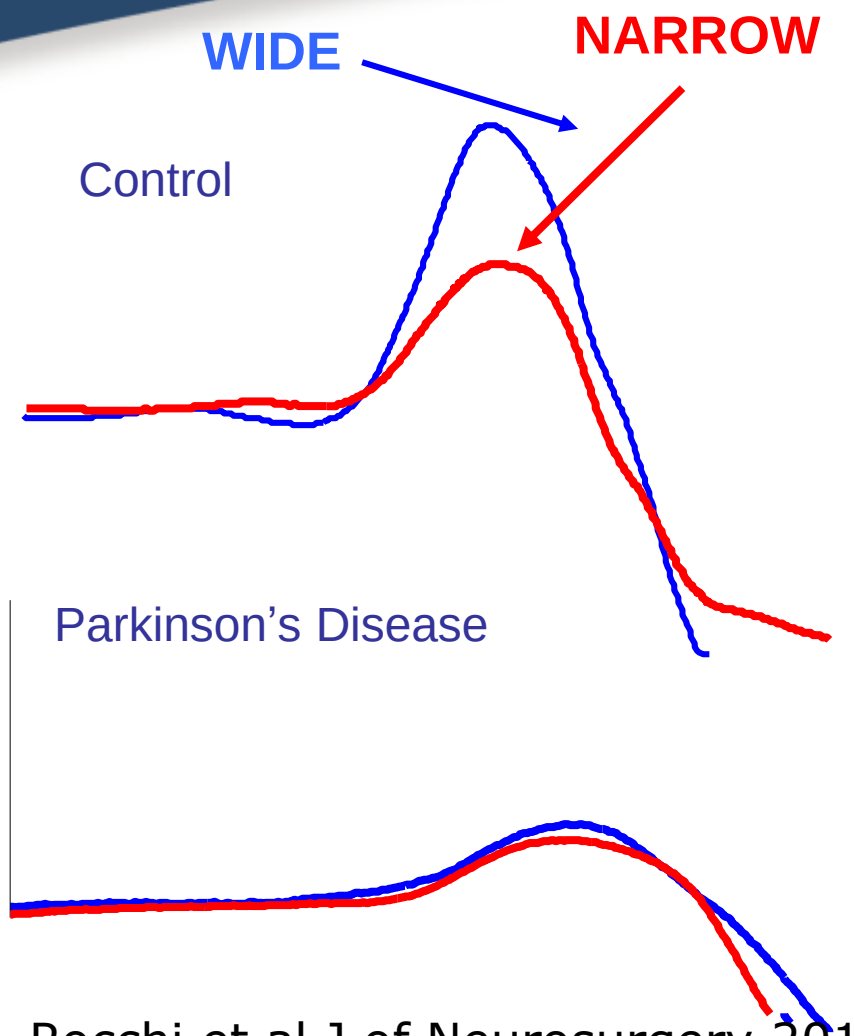
APAs don't get larger with wide stance in patients with PD



This may be the reason why stance width decreases with progression of PD!

Rocchi et al J of Neurosurgery 2012

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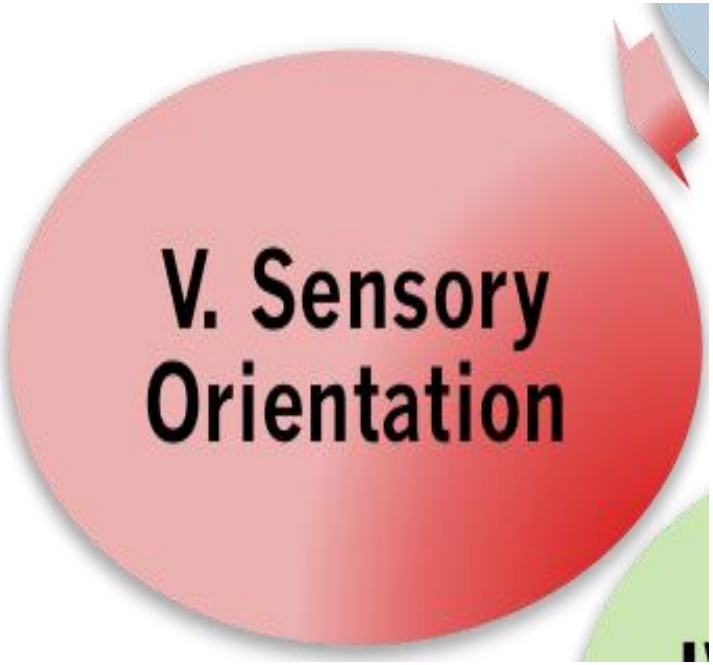

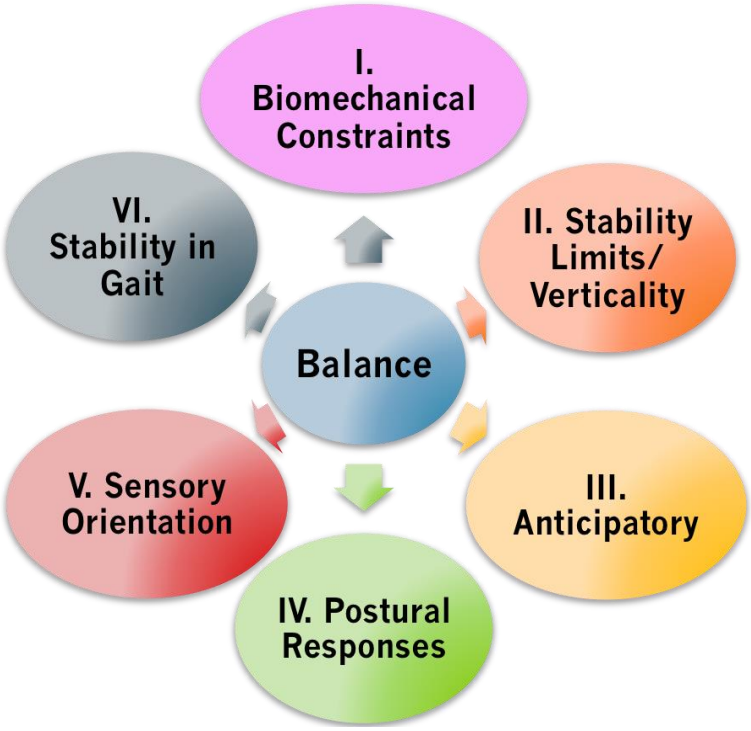

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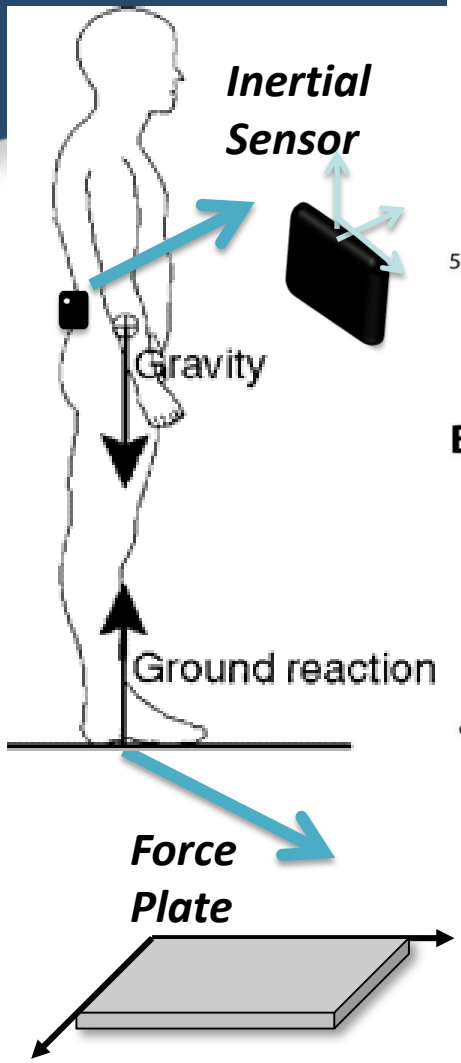
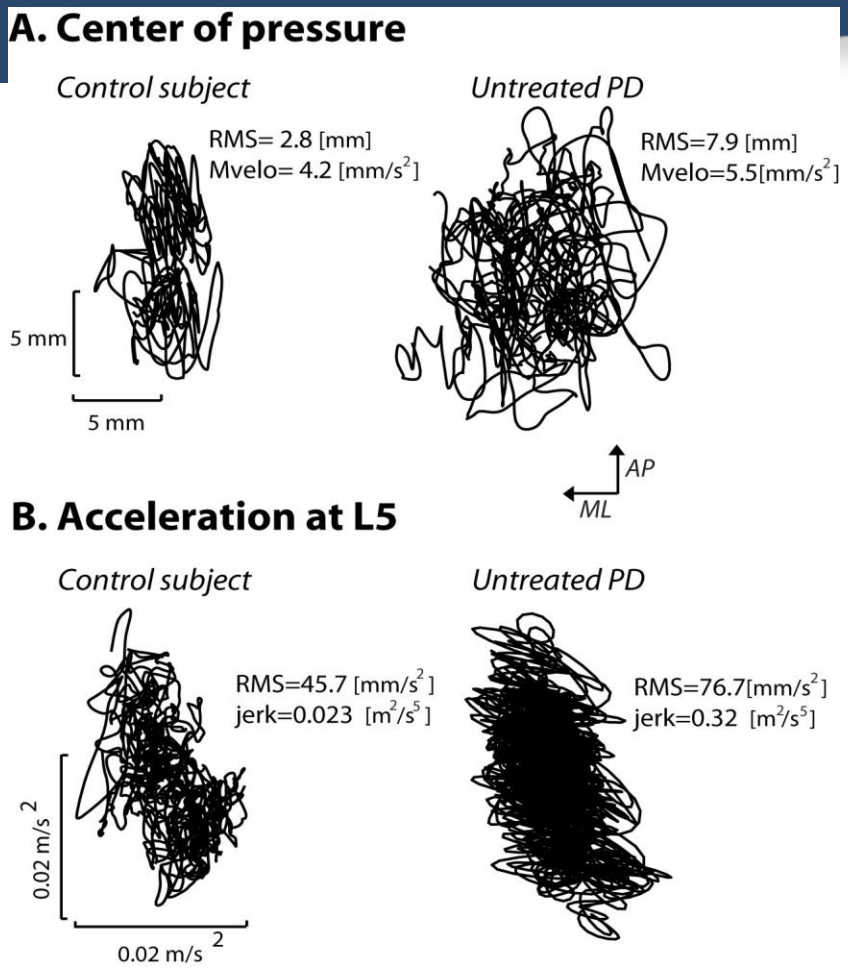
Postural Sway can be measured with Accelerometers





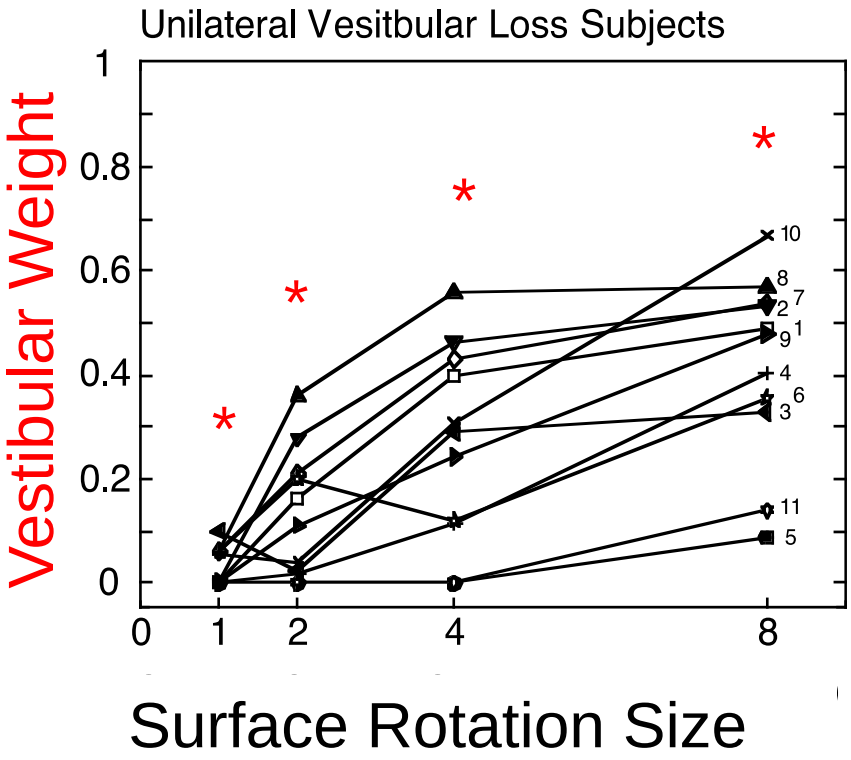
Mancini et al, 2009

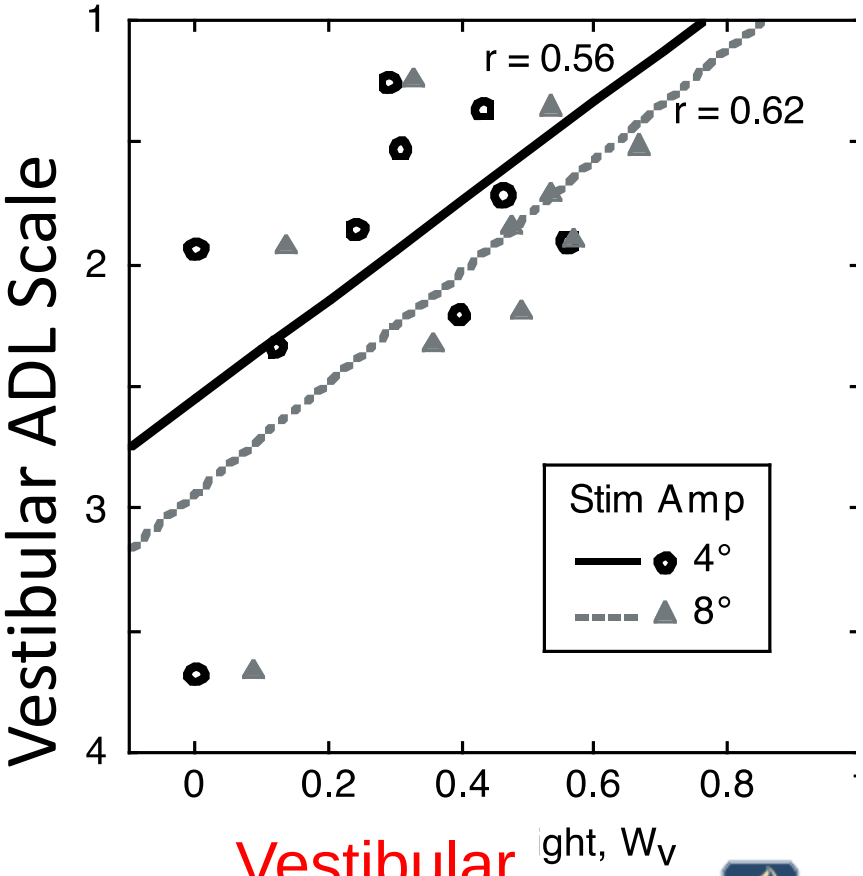
- **Sway area** (stability achieved by the postural control system)
- **Sway velocity** (amount of regulatory activity associated with this level of stability)

Sway jerkiness (derivative of acceleration, reflecting the amount of corrections)

Hufschmidt A et al., 1980
Maki BE et al., 1991

Unilateral vestibular loss who weight remaining vestibular show best ADL





Peterka, Wrisley, Statler, Horak,
Frontiers in Neurootology, 2011

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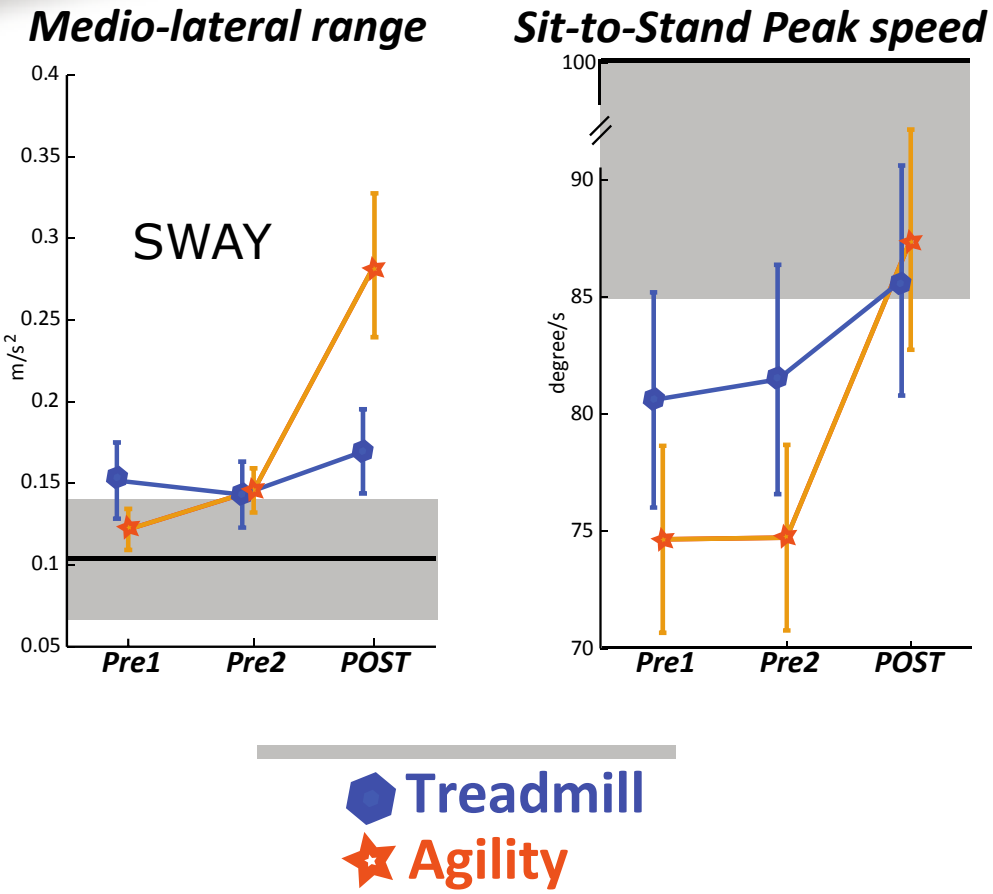
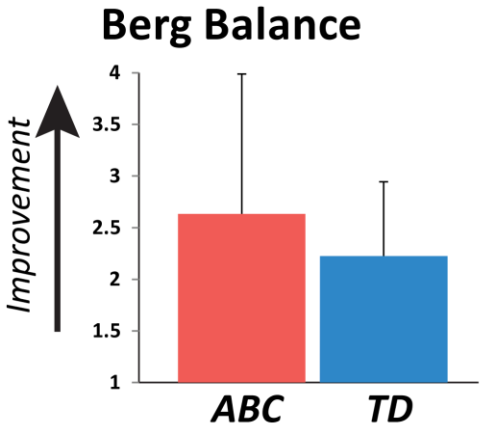
Instrumented postural sway may be more sensitive to rehabilitation than clinical measures





King, L.A. and Horak, F.B. Physical Therapy 2009

King, LA et al Parkinson's Disease, 2013

King, LA et al J of Neurological PD, 2012

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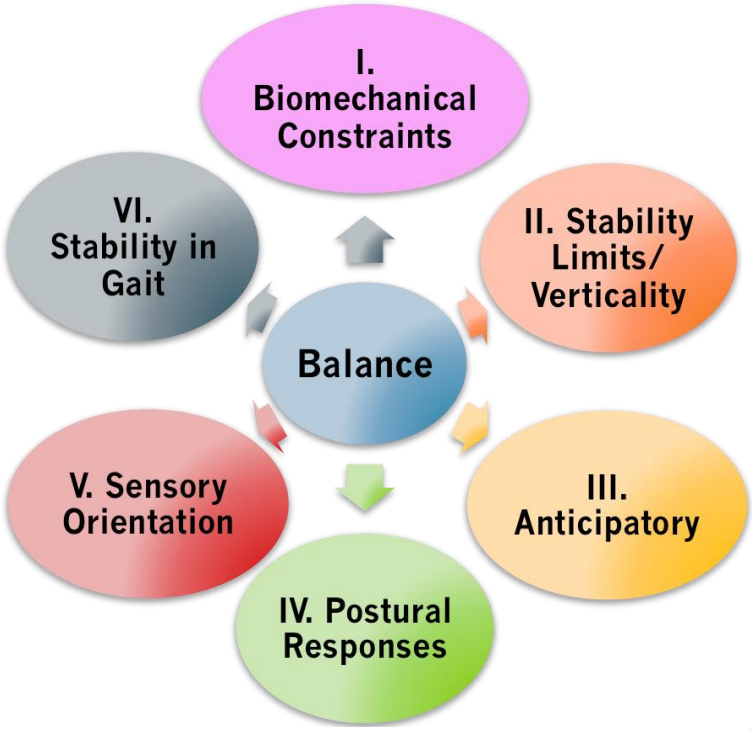

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Mobility impairments in patients with normal gait speed

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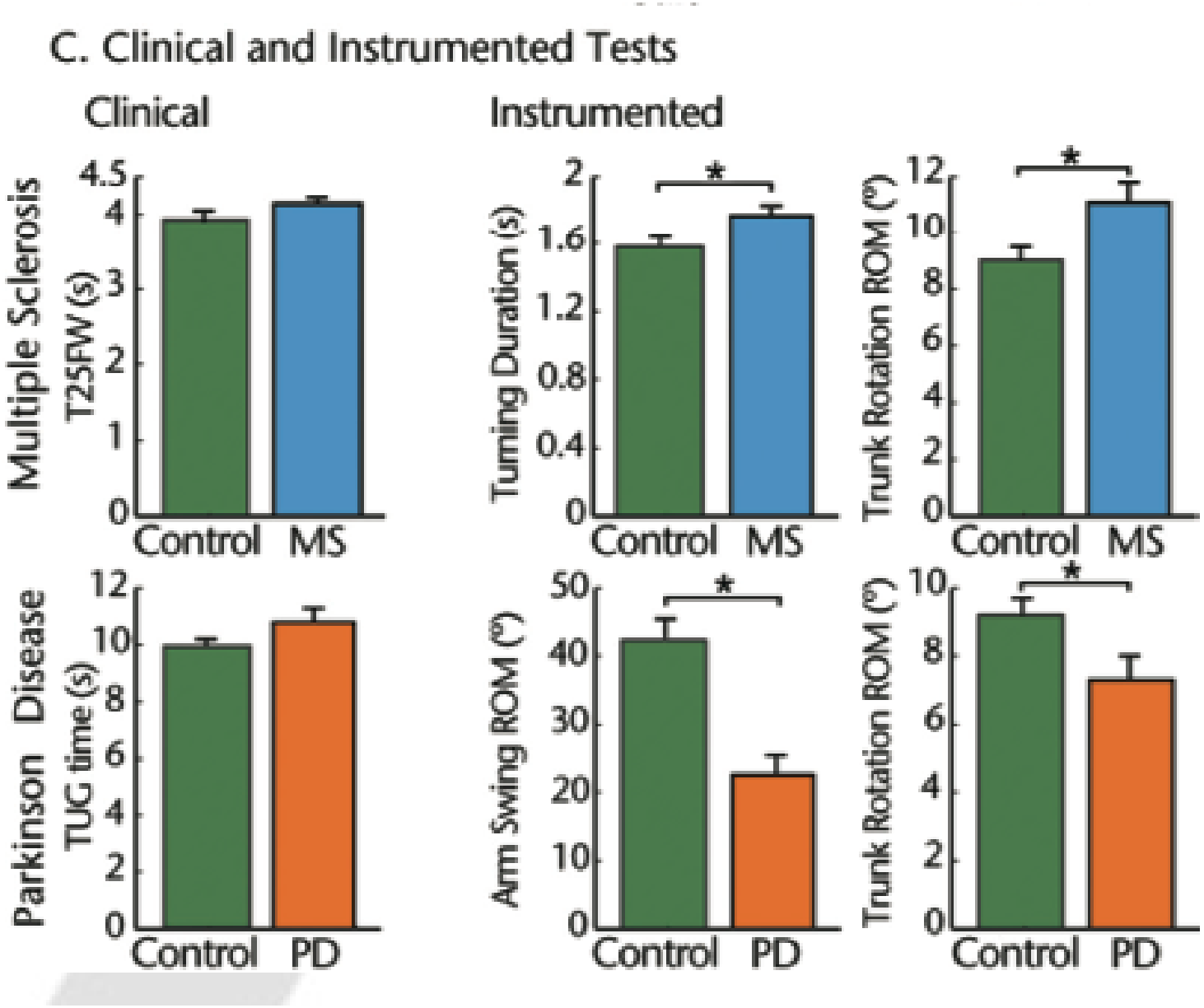


Objective measures are more sensitive than clinical tests to mild impairment

and more specific for disease

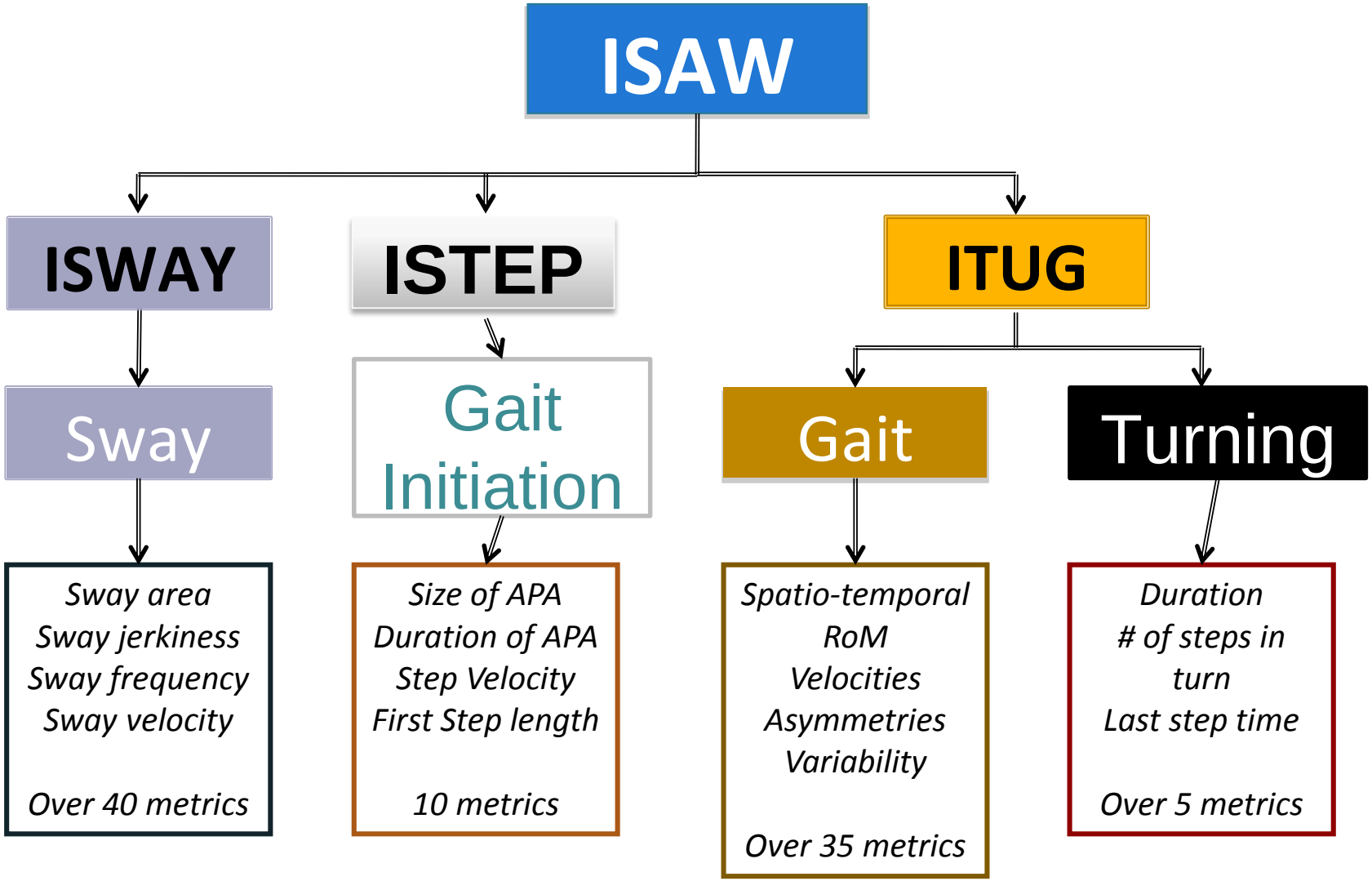
Zampieri et al, JNNR 2010
Spain, et al, Gait and Posture 2012

Instrumented gait for FALL RISK-

Verghese J Geronotol A 2009

Gait Measure	Median	All Falls Risk Ratio/p-V	Injurious Falls Risk Ratio p-V
Speed	95 cm/s	1.-08 / .003	1.05 / .25
Swing Time Variability	5.17% (sd/mean x 100)	1.007 / <.001	1.11 < .001
Stride Length	1123.5 cm	1.095 / .003	1.0 / .67
Stride Length Variability	3.6% (SD/mean x 100)	1.09 / <.001	1.13 / <.001
Double Support	26%	1.2 <.001	1.03 / .79

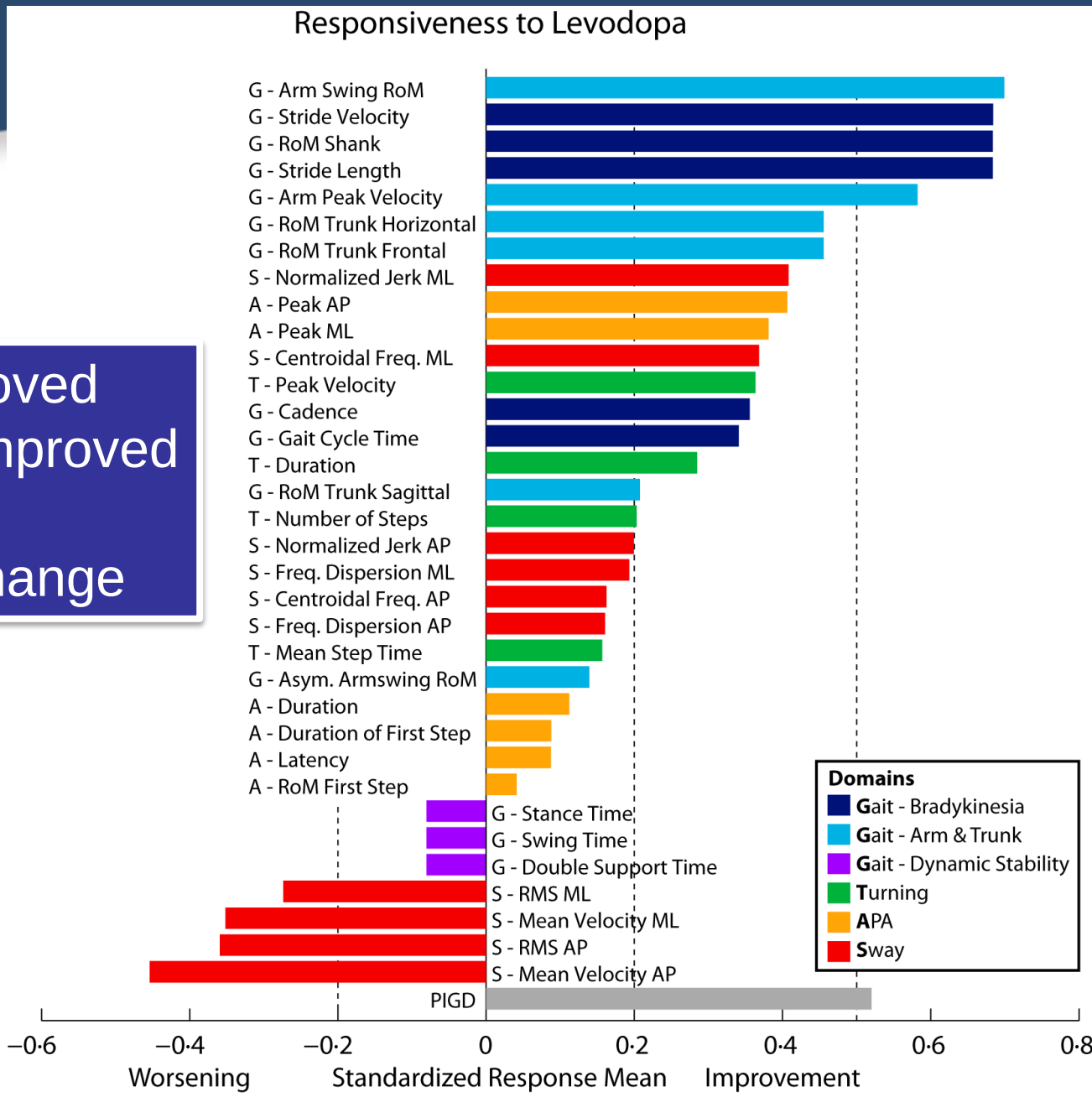
4 Balance Domains in a 1-minute test



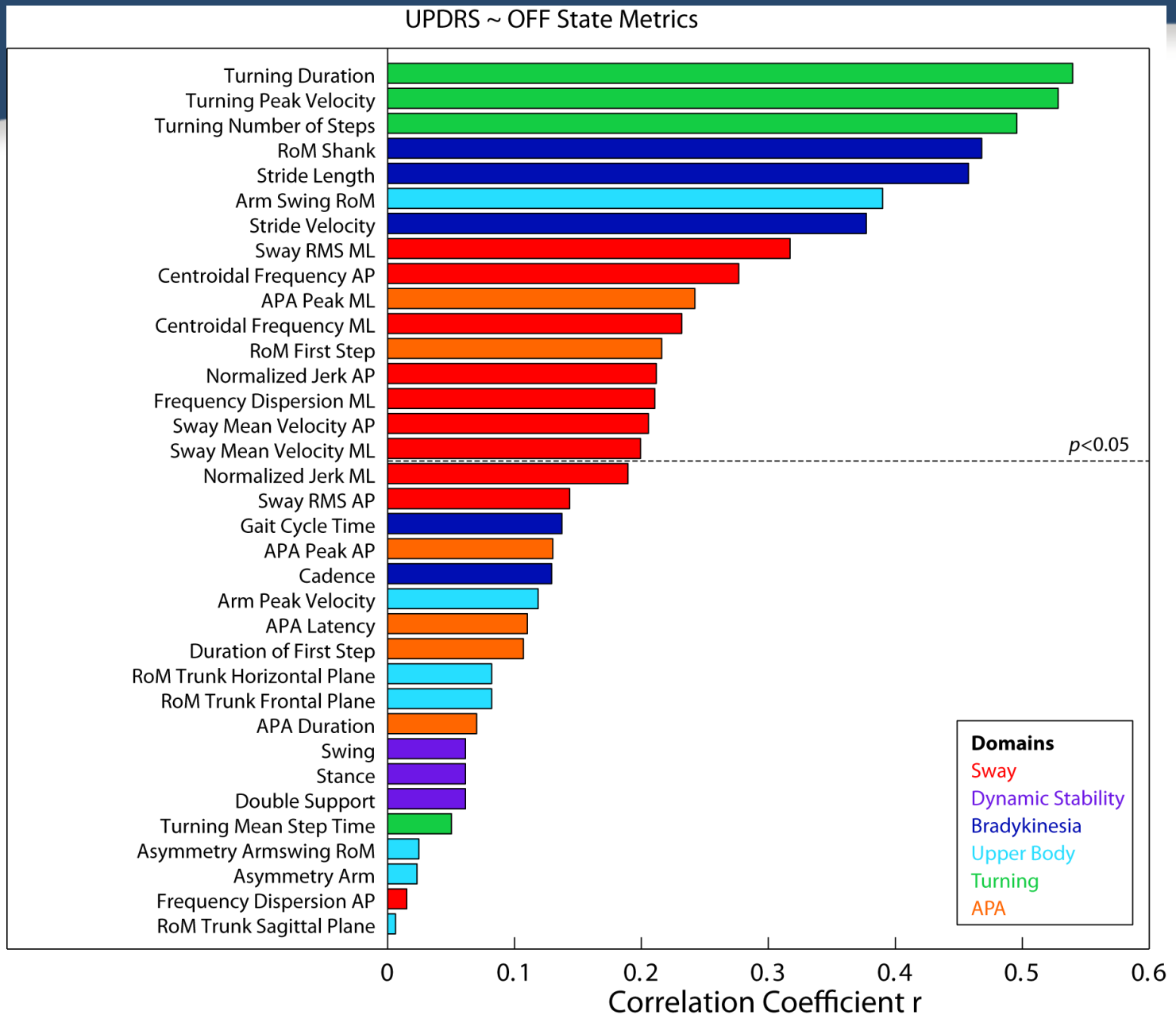
Responsiveness of balance and gait (ISAW) to levodopa

- Gait speed improved
- Gait arm/trunk improved
- Balance worse
- Gait timing no change

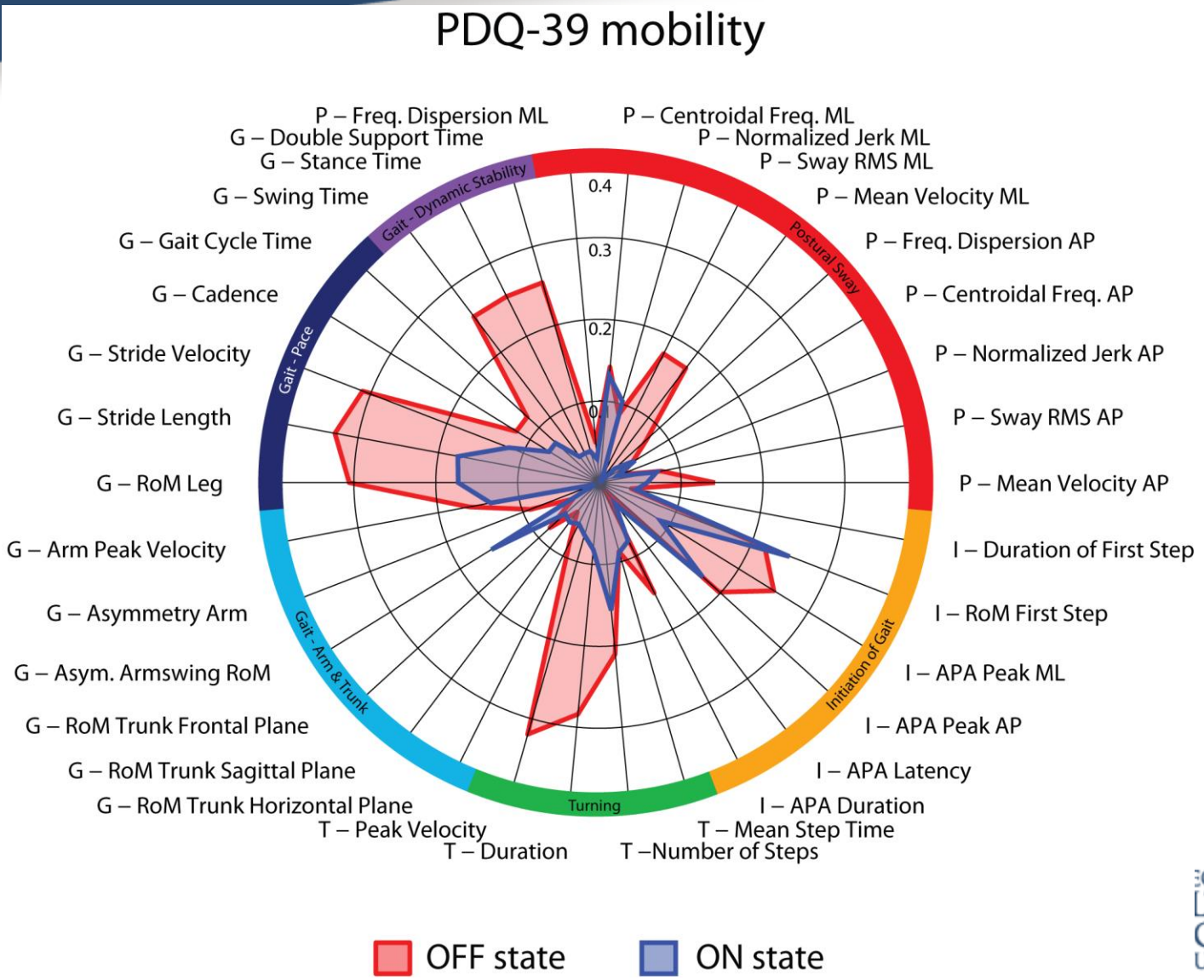
Curtze, et al
Movement Disorders
In Press



Turning is most sensitive to severity of PD



Turning, Speed and Stability related to Quality of Life



Do you want to know about your patient's mobility at home?

- More realistic
- Natural environments
- More dual-tasks
- How sedentary or active
- Fluctuations/variability
- Better predictor of falls
- Need to come back
  for "tune-up"

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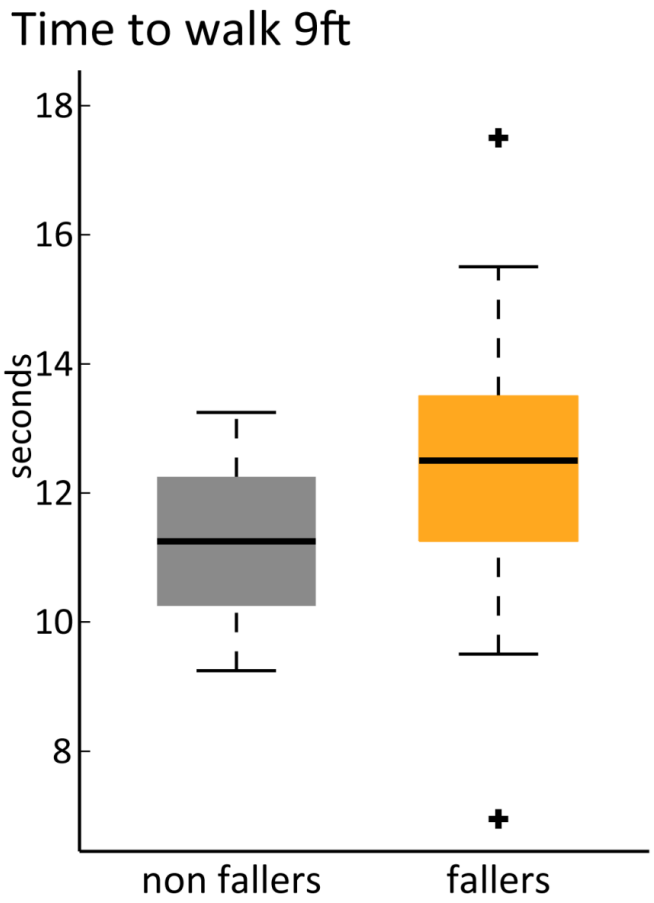
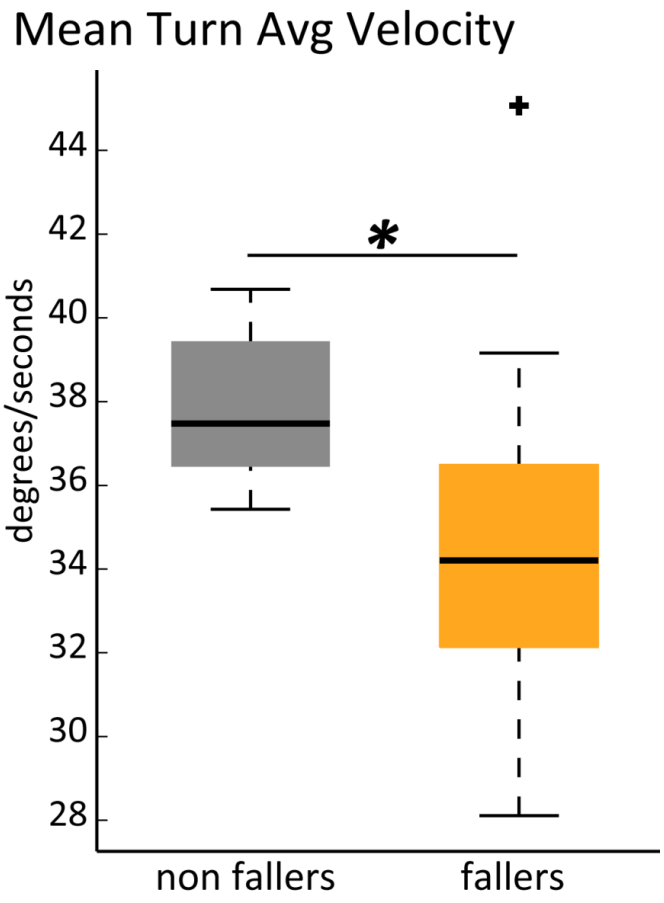
Characterizing Turning in the home with inertial sensors

Continuous monitoring of turning predicts future falls better than gait speed!





Mancini, et al

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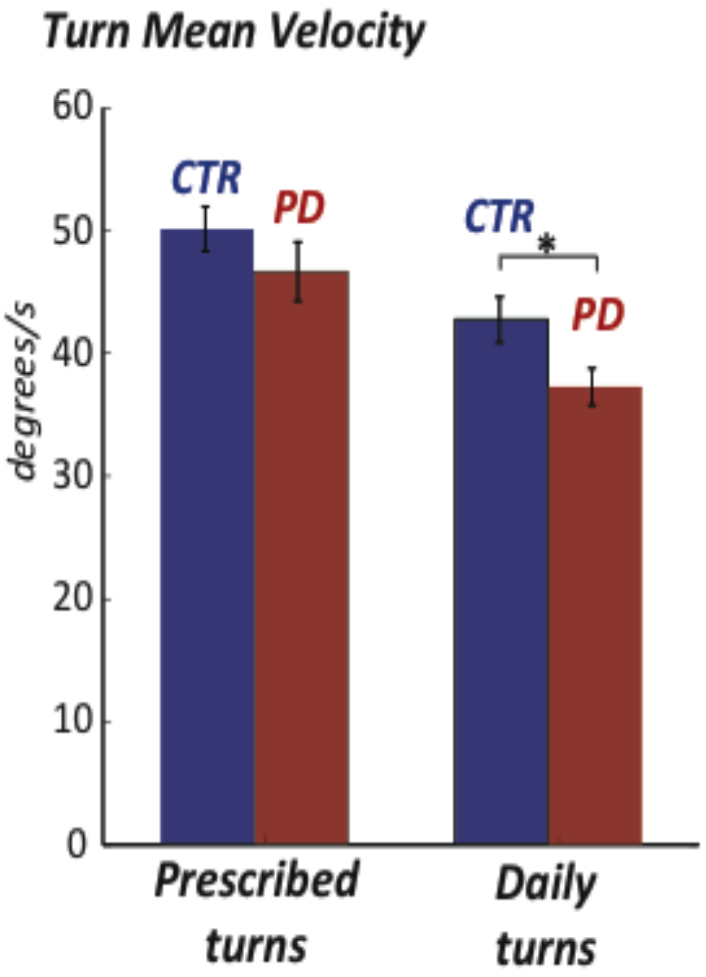
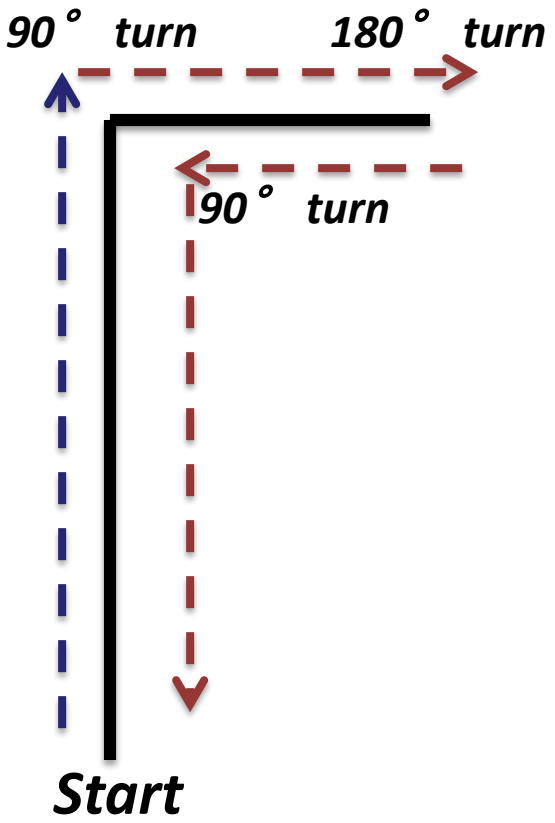
Turn velocity differs in daily life but not in prescribed turns



Prescribed Turning Test



Mancini et al
Neurorehabilitation in press

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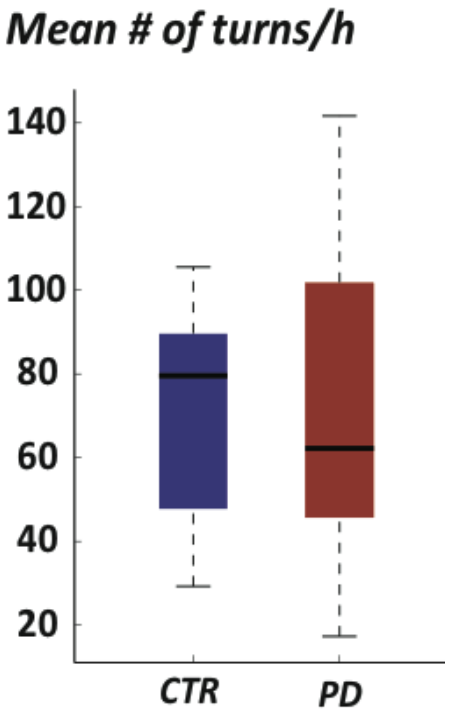
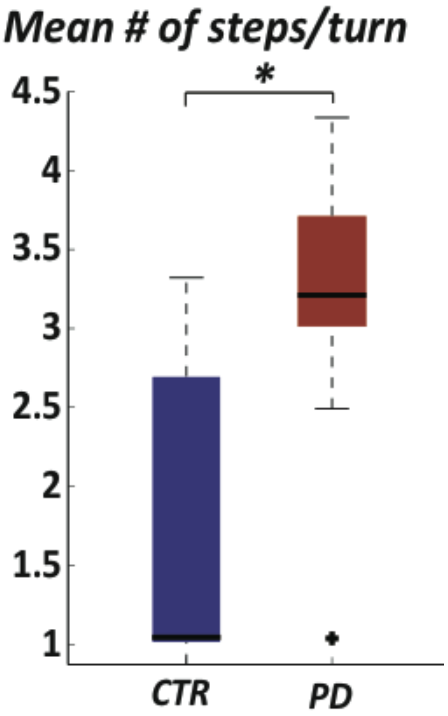
Quantity of activity is similar in PD and controls, but quality of turning is different

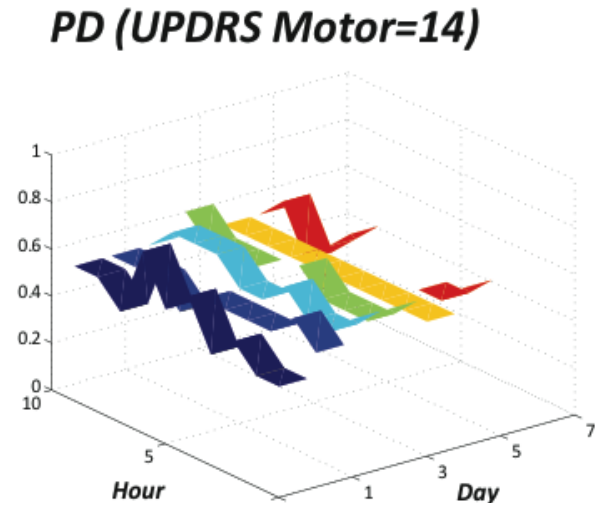
QUANTITY

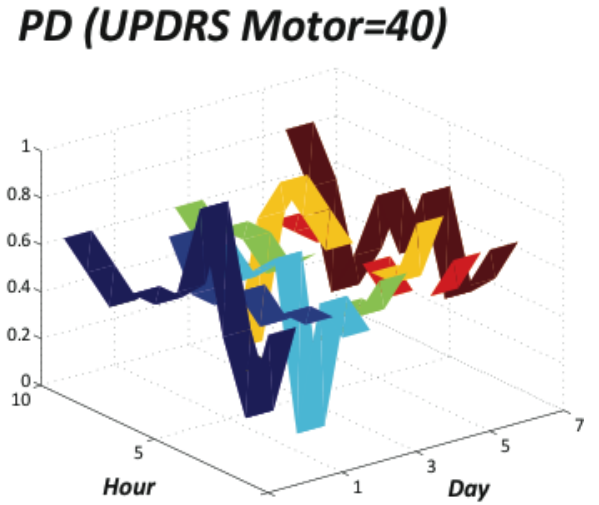


QUALITY



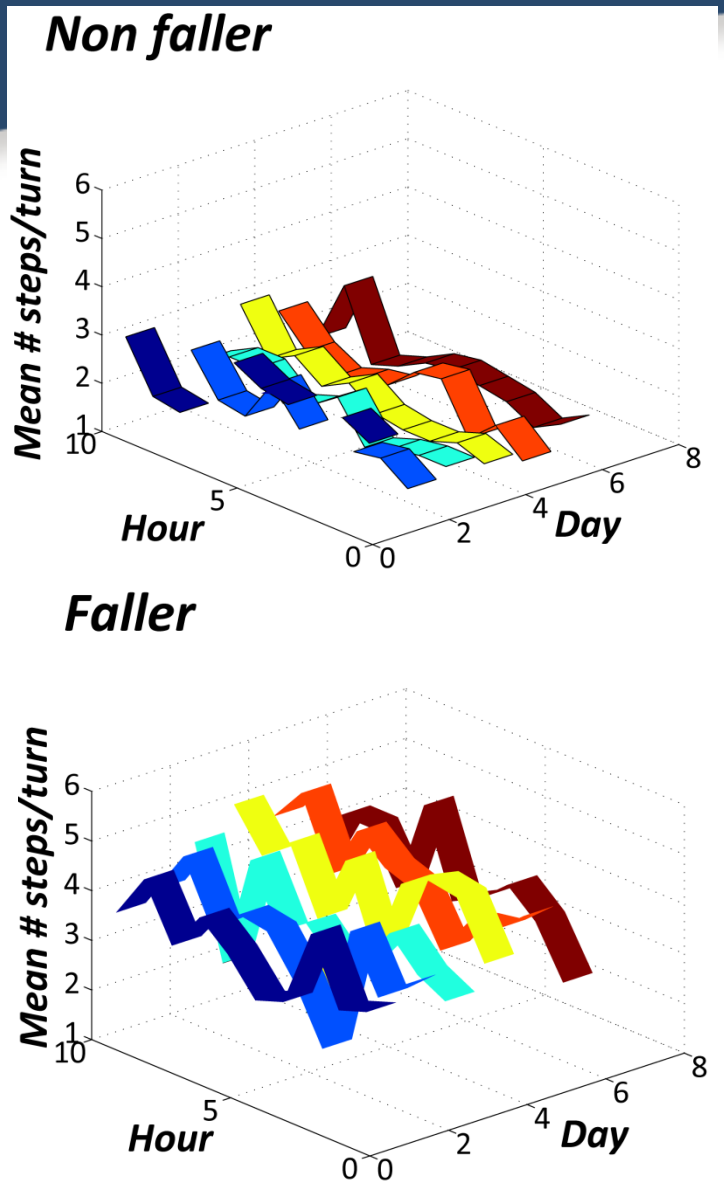
VARIABILITY

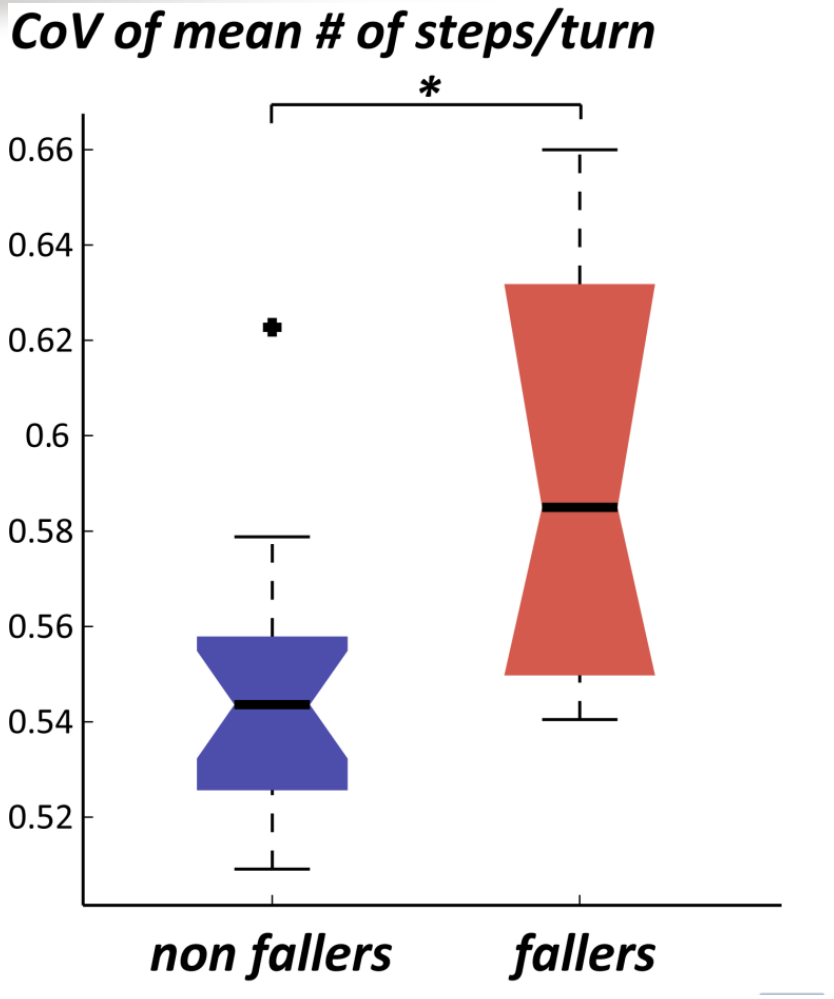




Mancini et al
Neurorehabilitation in press

Variability of turning predicts prospective falls

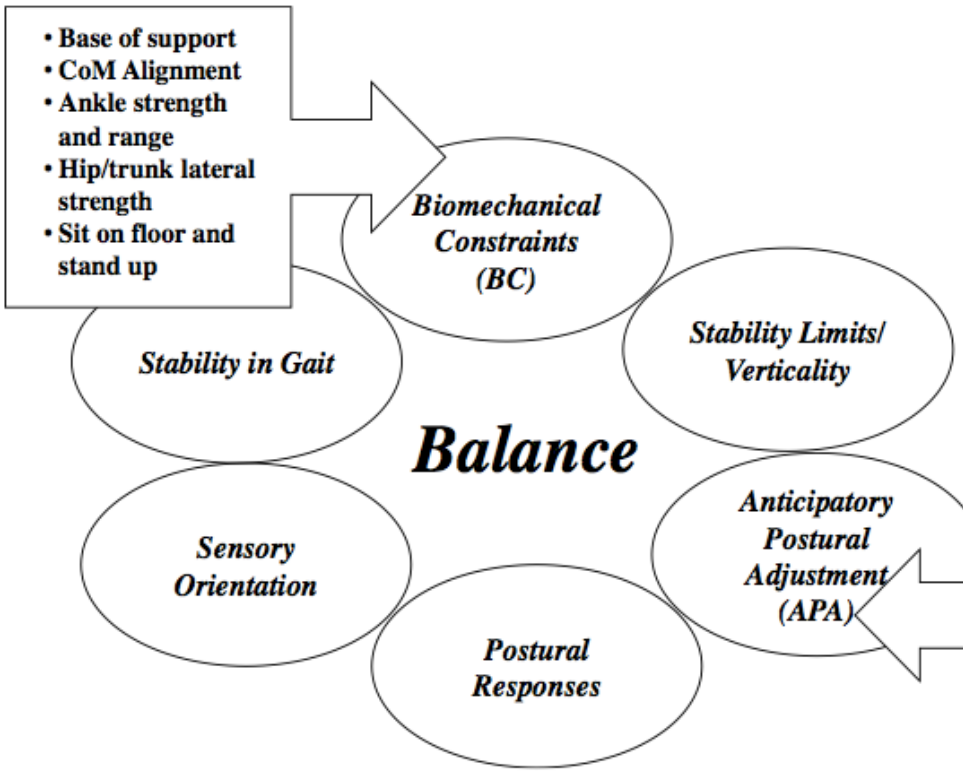


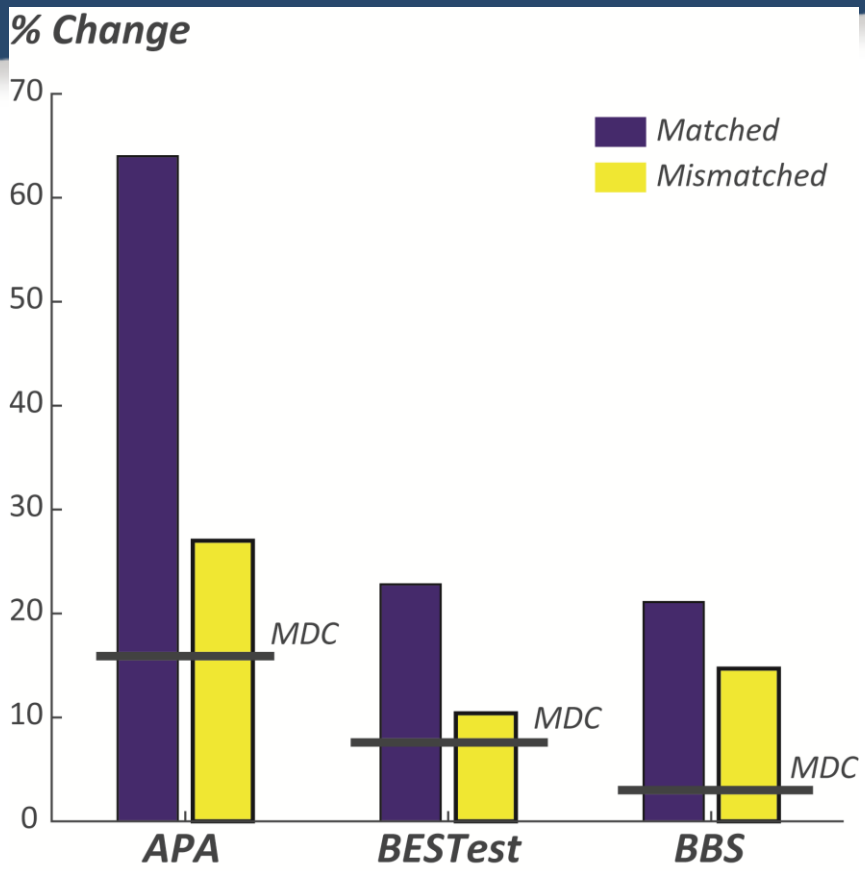


Mancini et al J of Gerontology, Med Sci Submitted

Does targeting balance training to specific ‘ impairments help?

Elizabeth Wang-Hsu, 2015
Thesis Drexel University





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Can we target cognitive function to improve mobility?

✓ ***Agility***

✓ ***Agility-Cogniitve***

✓ ***Executive function***

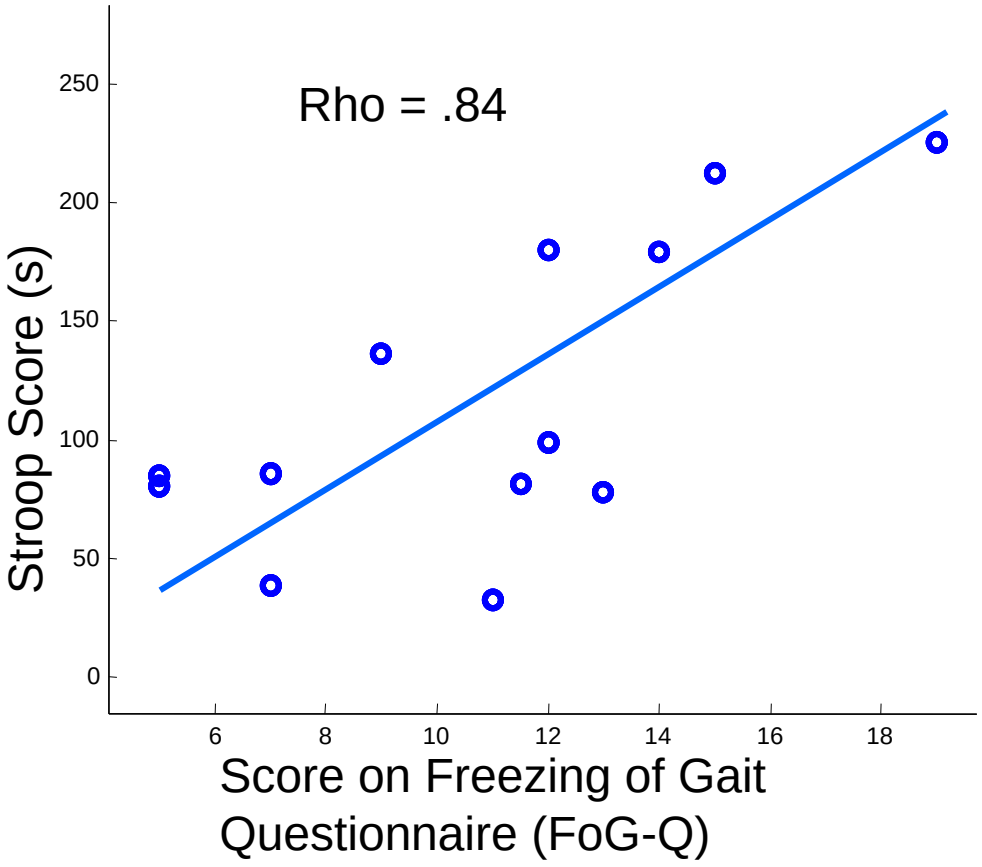
Inhibition	Set-Shifting	Updating
Stroop task	*Plus-Minus task*	*Backward Digit Span task*
Go-no go task	*Berg Card Sorting task*	*Letter Memory task*
Flankers task	*Trail-Making task*	*Random Number Generation task*

King and Horak
Physical Therapy
2011; 2013

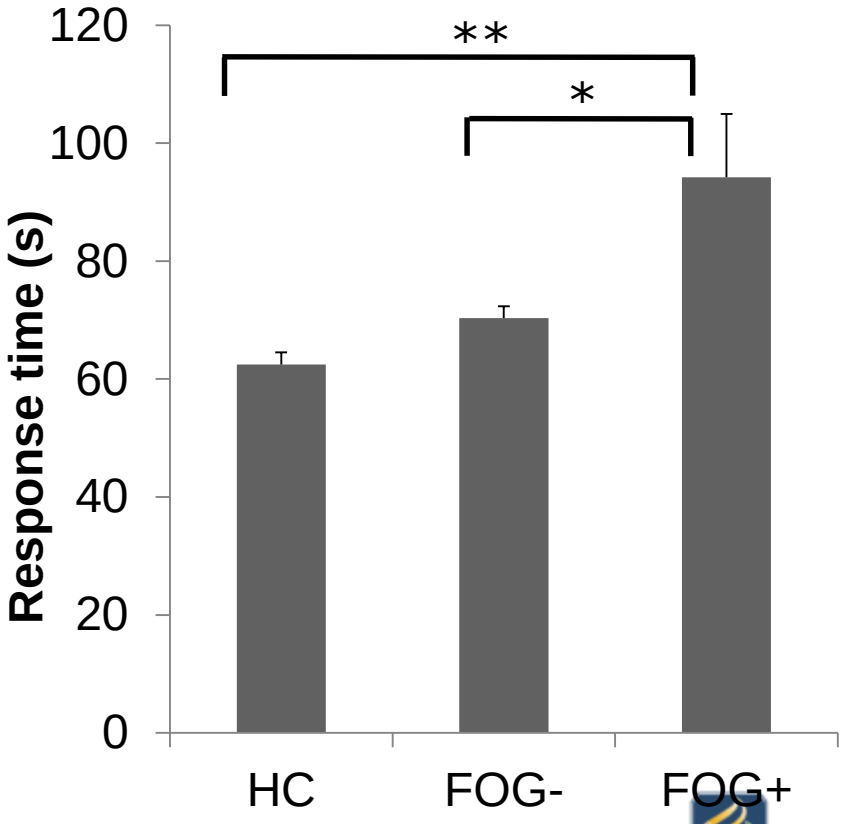
Delaying Mobility Disability in People With Parkinson Disease Using a Sensorimotor Agility Exercise Program

Executive Inhibition is related to FoG

Cohen, Nutt and Horak, 2013



Stroop Conflict



Stroop: Name the Colors!

Blue Green Purple Green

Impairment of cognitive inhibition could contribute to FoG

- In gait, lifting of the stepping leg must be delayed until the postural weight shift is complete.
- Failure to release inhibition of the stepping program and to inhibit the postural preparation may lead to FoG.
- **Is the response inhibition circuit impaired in FoG?**

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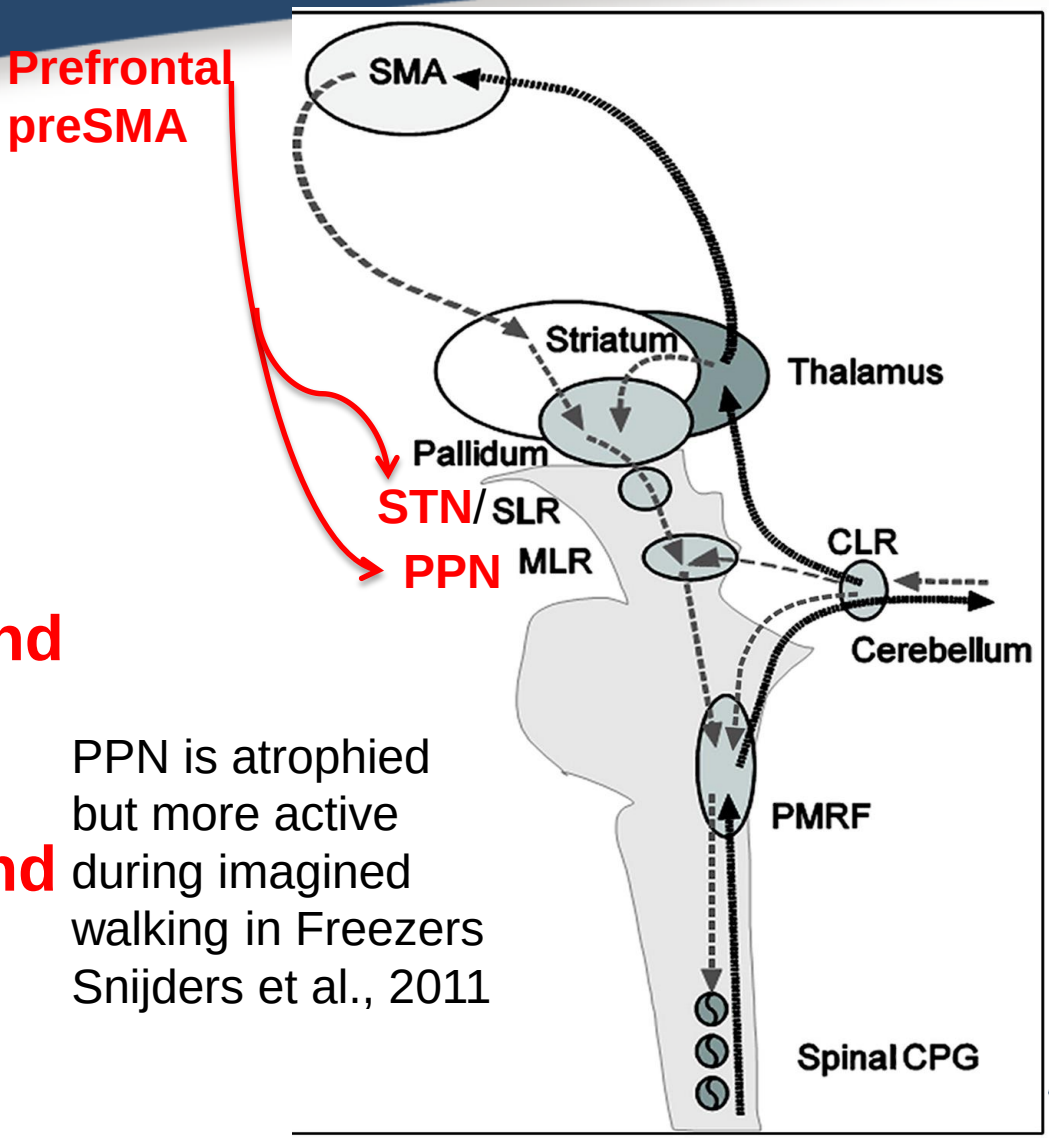
Posture/Locomotor Network

Hypothesis:

FoG is due to abnormal connections between Medial-Frontal Cortex and Midbrain Locomotor Centers (PPN) and STN



PPN is atrophied but more active during imagined walking in Freezers Snijders et al., 2011

Fougere et al, NeuroImage 50:1589, 2010

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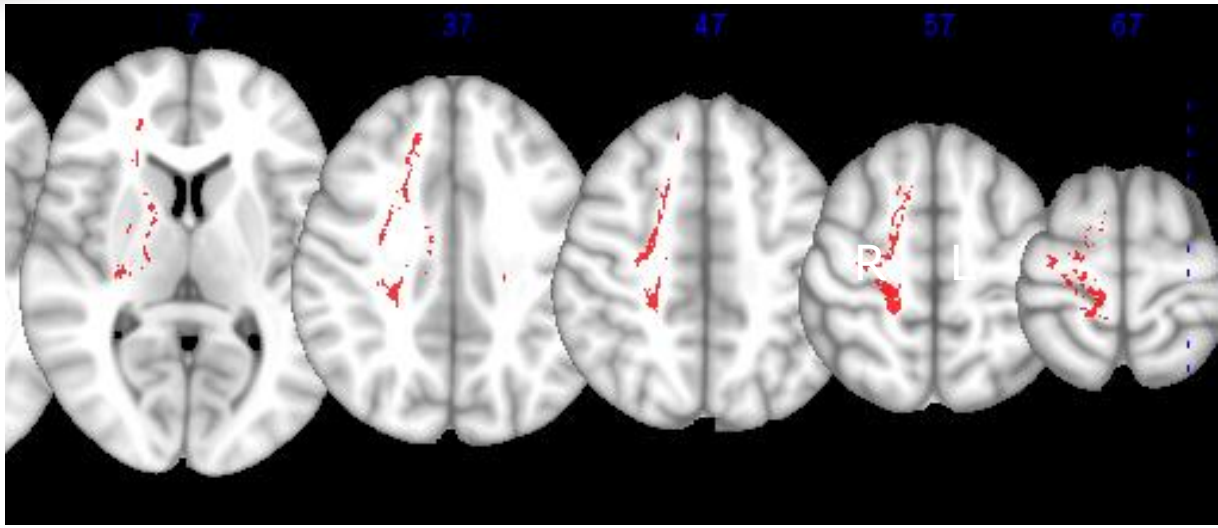
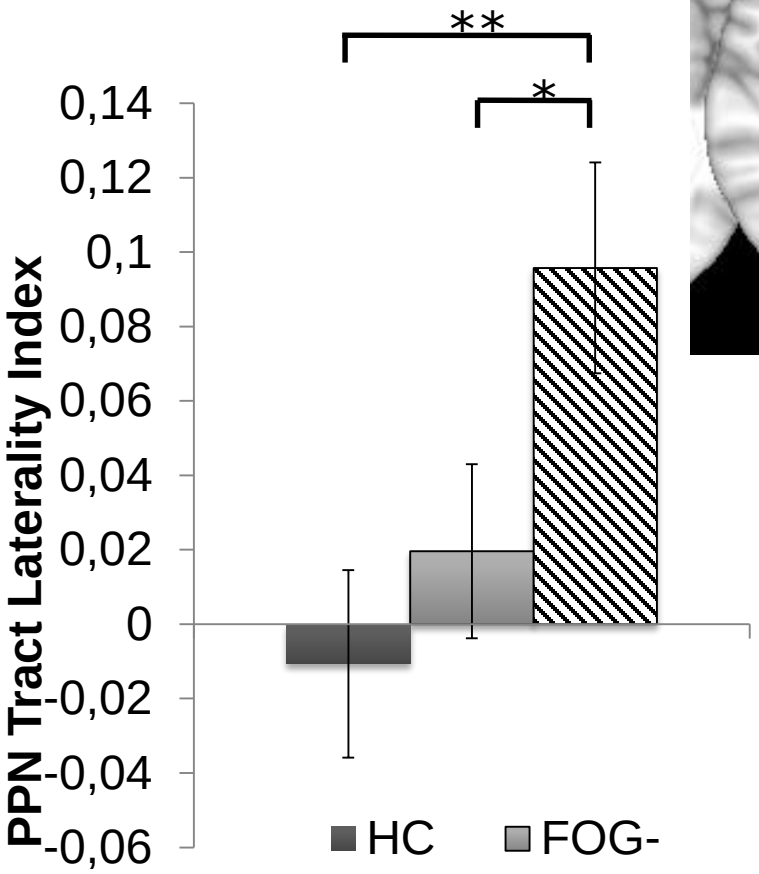
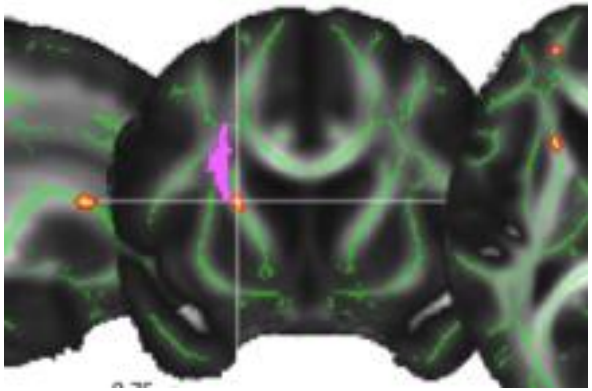
Missing white matter of the Right Locomotor (Response Inhibition) Network in Freezers

Fling and Horak, *Brain 2013*





Response Inhibition Circuit:
Right STN-PreSMA Healthy



Coxon, et al, J Neurosci 2012

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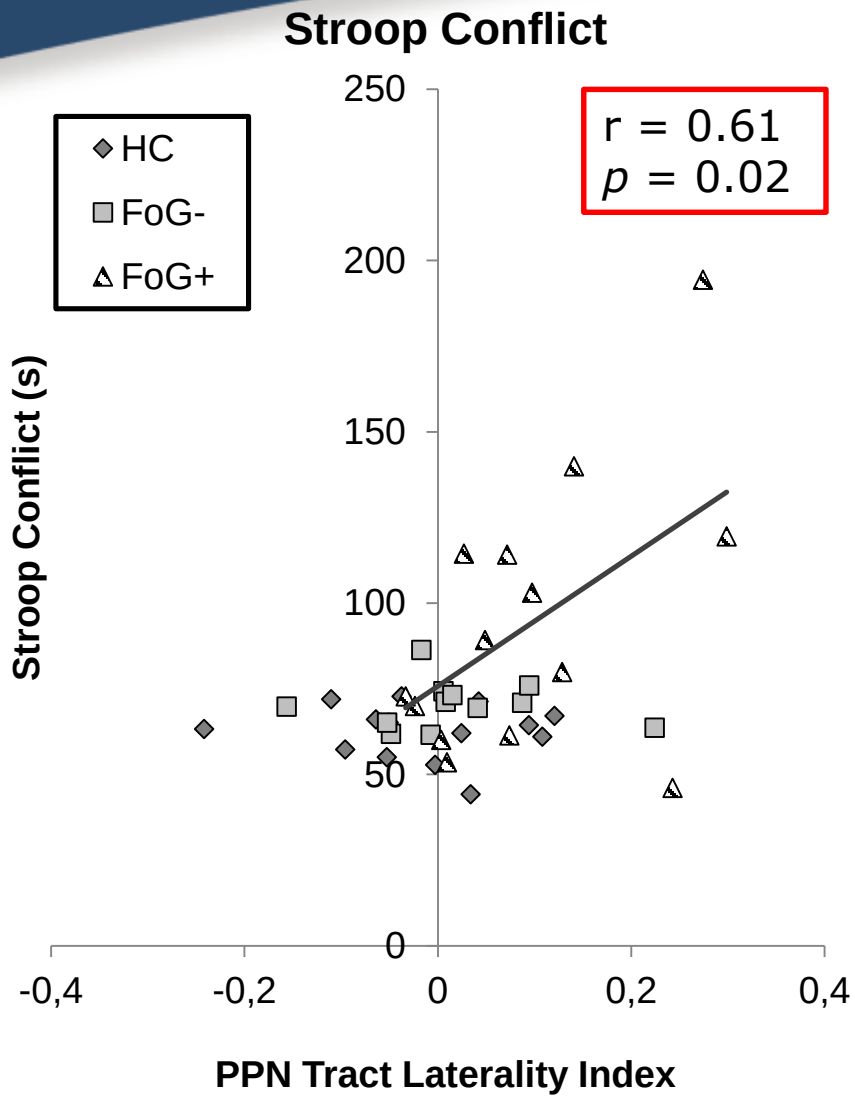
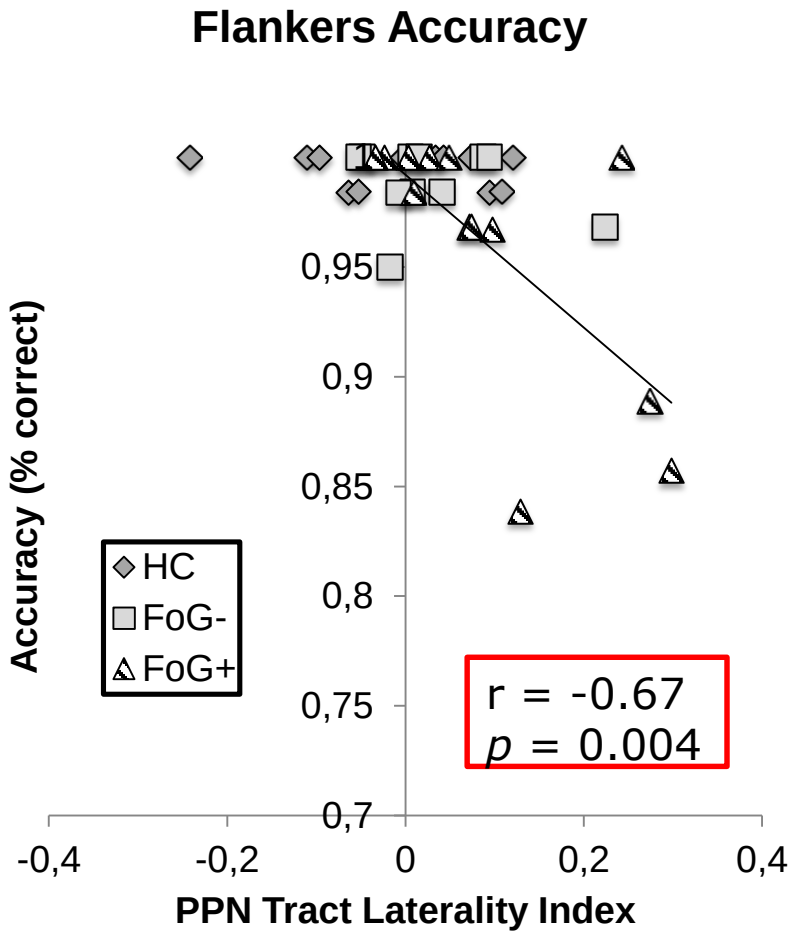
Asymmetry of white matter from PPN to medial frontal relates to Executive Inhibition in FoG+



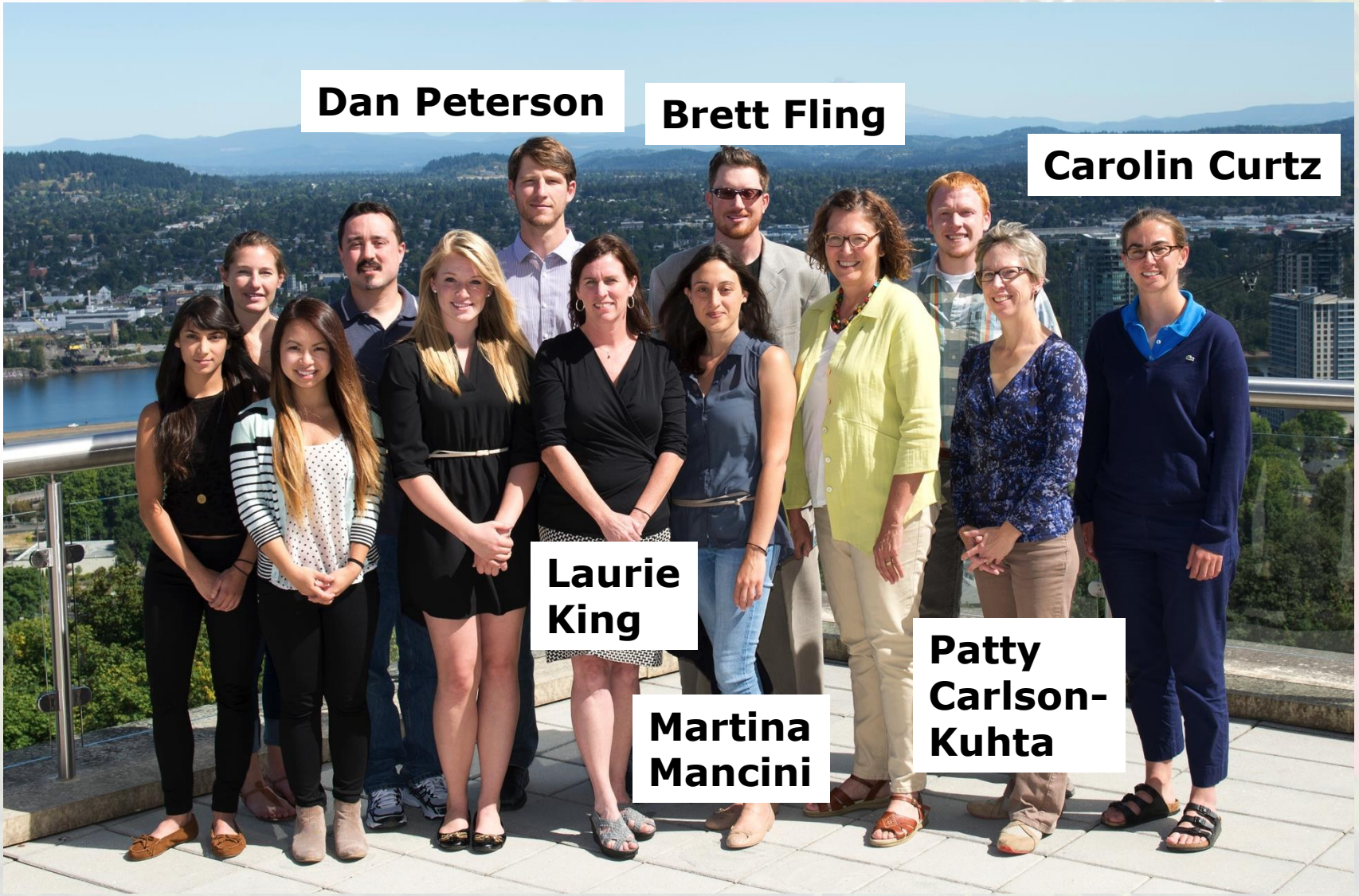


Fling et al. *Brain 2013*

CONCLUSIONS

- A systems approach to balance can identify specific impairments for rehabilitation to target
- Objective measures of impairments are more sensitive to mild impairments than clinical measures of function
- Continuous monitoring of mobility adds value
- Cognitive impairments contribute to mobility disability

Balance Disorders Lab OHSU



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Posture and Gait in Research, Clinic and Sport

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