



Function of Gait in Movement Disorders

Seoul, Korea | October 3, 2026



International Parkinson and
Movement Disorder Society
Asian & Oceanian Section

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Standardizing Gait and balance Assessment

PROF. ANAT MIRELMAN

LABORATORY OF EARLY MARKERS OF NEURODEGENERATION (LEMON)
NEUROLOGICAL INSTITUTE, TEL AVIV MEDICAL CENTER
GRAY FACULTY OF MEDICINE AND SAGOL SCHOOL OF NEUROSCIENCE.
THE AUFZIEN FAMILY CENTER FOR PREVENTION AND TREATMENT OF PARKINSON'S DISEASE, TAU



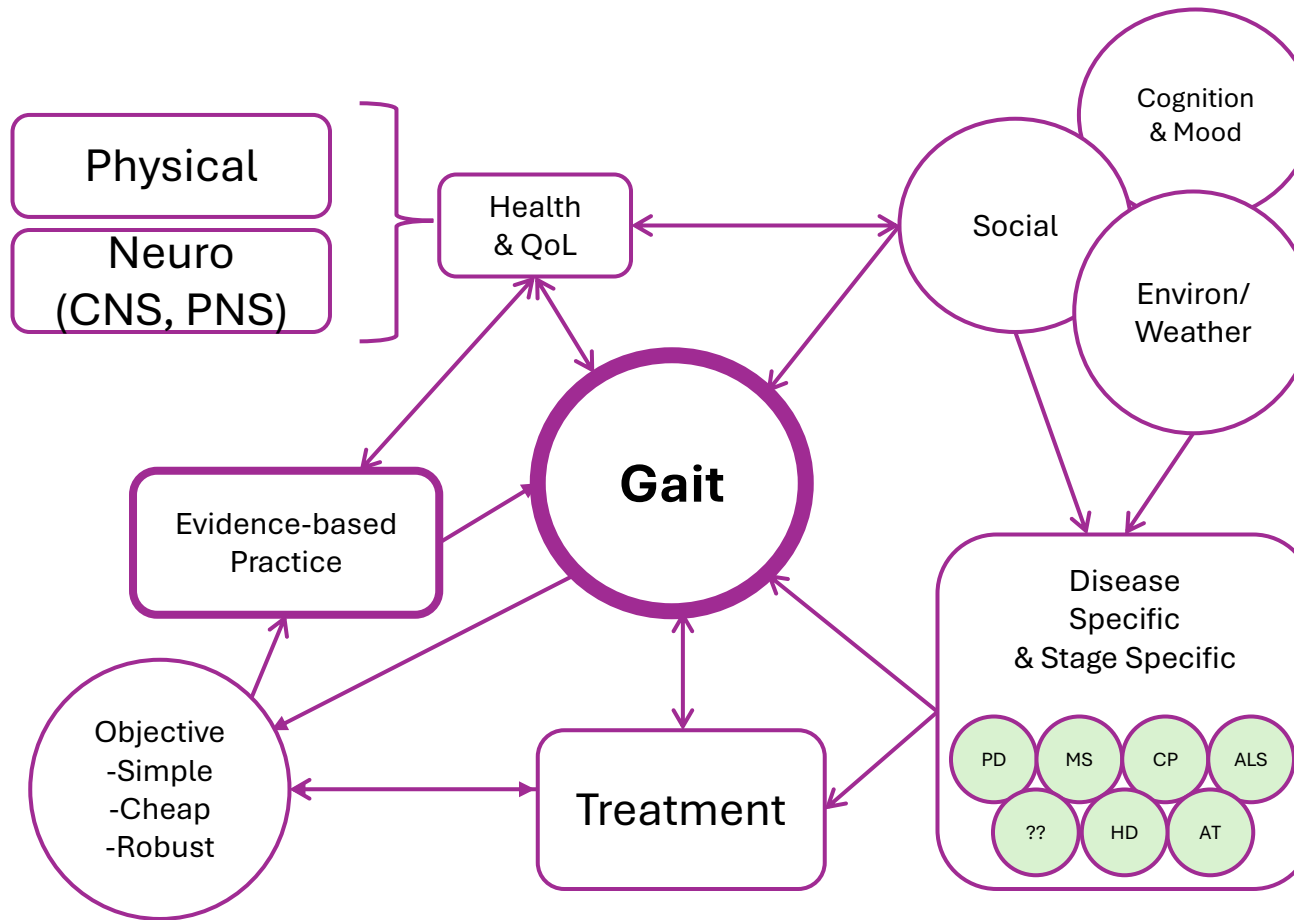
LEMON
Laboratory for Early Markers of
Neurodegeneration



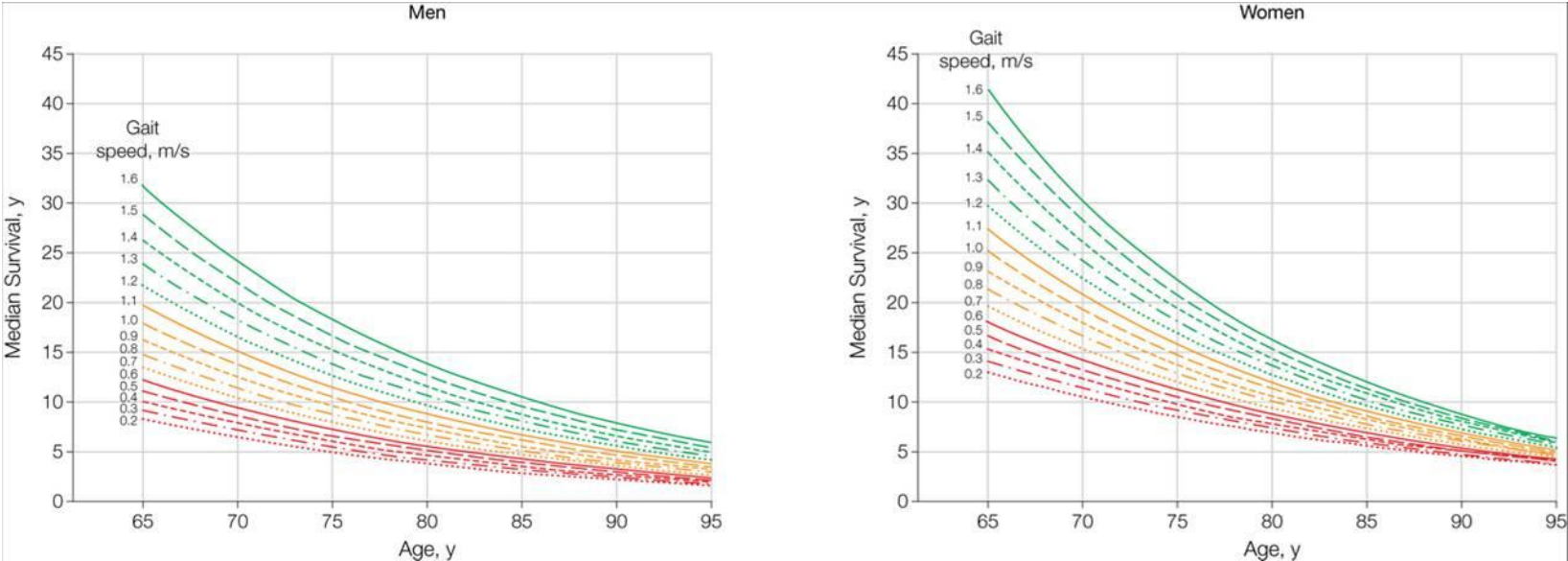
Disclosure

Nothing to disclose pertaining this presentation

Why measure gait function?



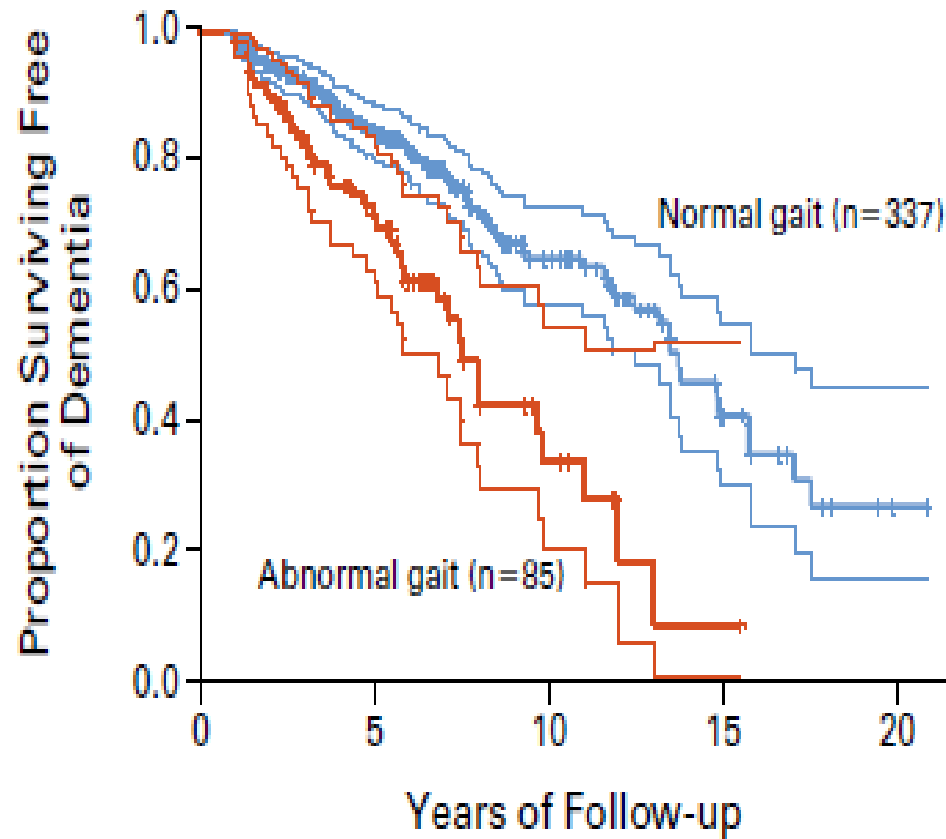
Gait speed associated with survival



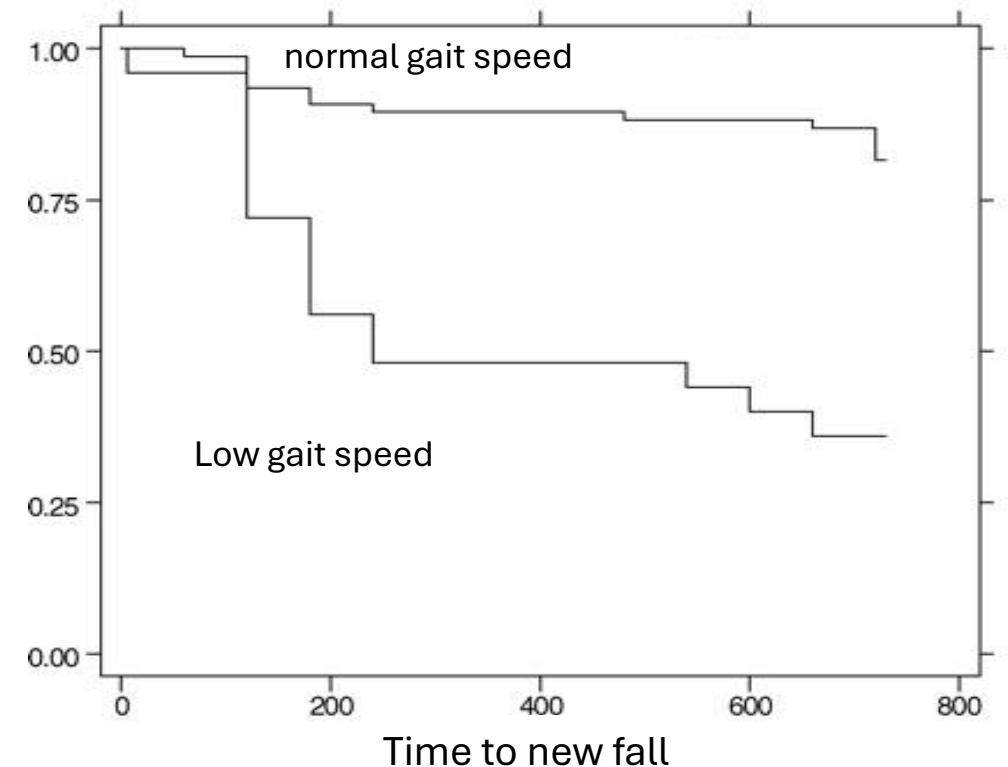
	Men		Women	
Walking Speed	1 mph	1 mph	3.5 mph	3/5 mpg
Probability that an 80-year-old will live to age 90	10%	23%	84%	86%
Median life expectancy for an 80-year-old (in years)	84	87	94	97



“Footprints to Cognitive Decline and Alzheimer’s are seen in Gait”



Gait speed associated with fall risk



Gait in Parkinson's disease

- Gait disturbances play a major role in the motor manifestation of PD and among the most common and disabling PD symptoms.
- Gait changes frequently observed include decreased stride length and an increased stride time variability even early in the disease.



Clinical gait recommendations from the American Neurological Physical Therapy

Research

2 minute walk test

6 Minute walk test

ABC scale

Berg Balance Scale

BESTest/ MiniBESTest

Dynamic Gait Index

Four square step test

Freezing of Gait Questio

Functional Gait Ass

Functional reach test

Gait Speed (10m walk test)

MDS-UPDRS revision

Modified Gait Efficacy Scale Physical

Performance Test (PPT)

Performance Test (CS-PFP)

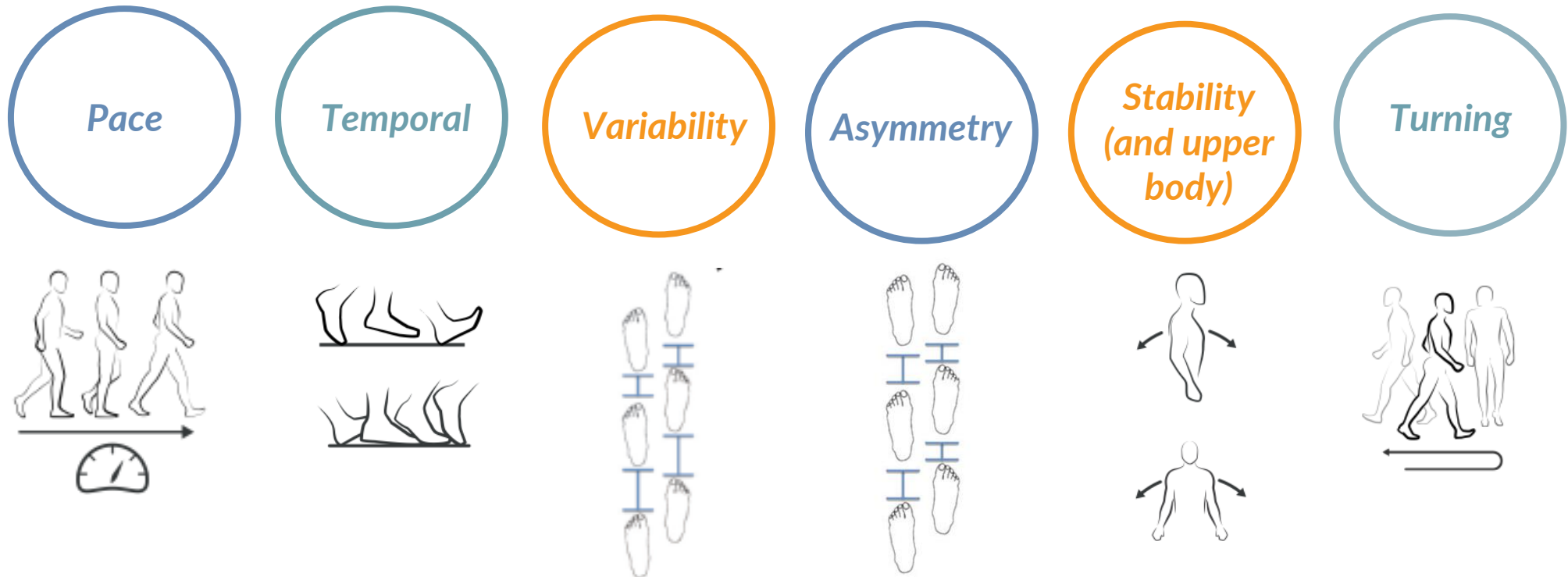
Sit to stand 5 times

Core Set

- *Berg Balance Scale*
- *Functional Gait Assessment*

Easy to obtain BUT
Focus on gait speed or capacity which is
not the full picture in PD

Gait is not only speed



Classification of Gait Disturbances in PD

Continuous Features

- Short stride length
- Slow walking speed
- Shuffling pattern
- Unsteady / fearful gait
- Dyskinetic-dystonic features
- Stooped posture
- Reduced arm swing
- Asymmetry

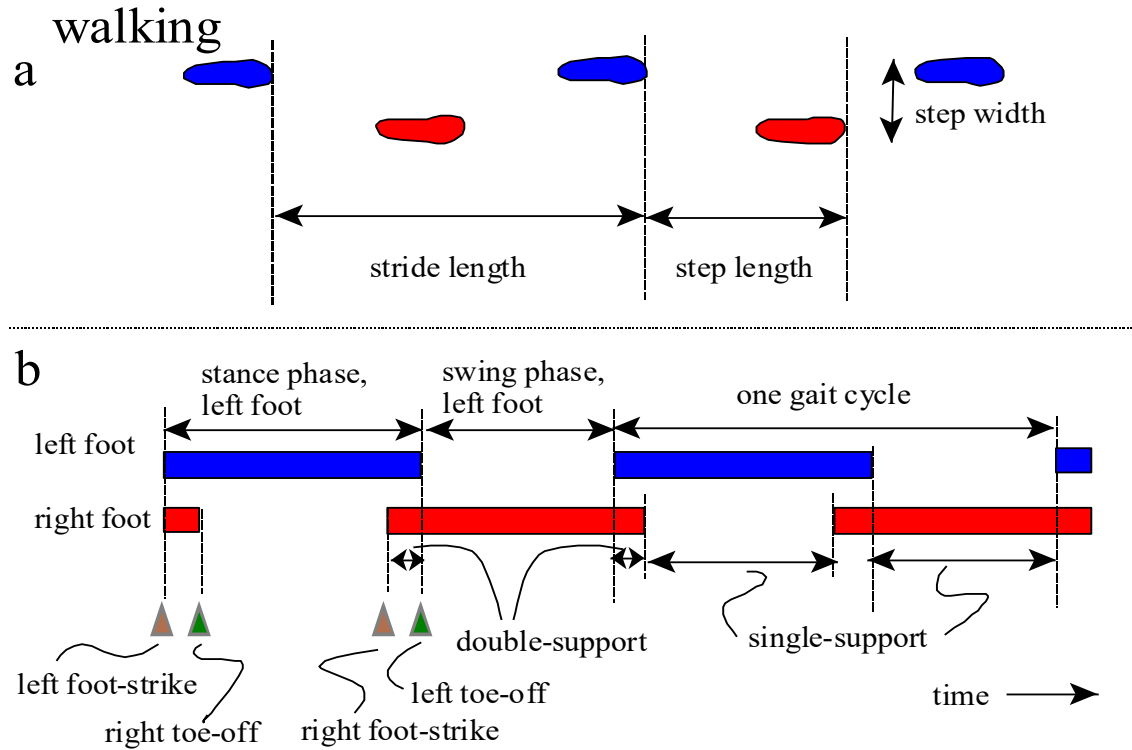
Episodic Features

- Freezing of gait (FOG)
- Festination
- Near-falls
- Falls



Episodic events are less predictable and often more disabling than continuous features.

Clinic based assessment of gait disorders in PD



A

Slowness of gait

- Hypokinesia
- Bradykinesia
- Rigidity

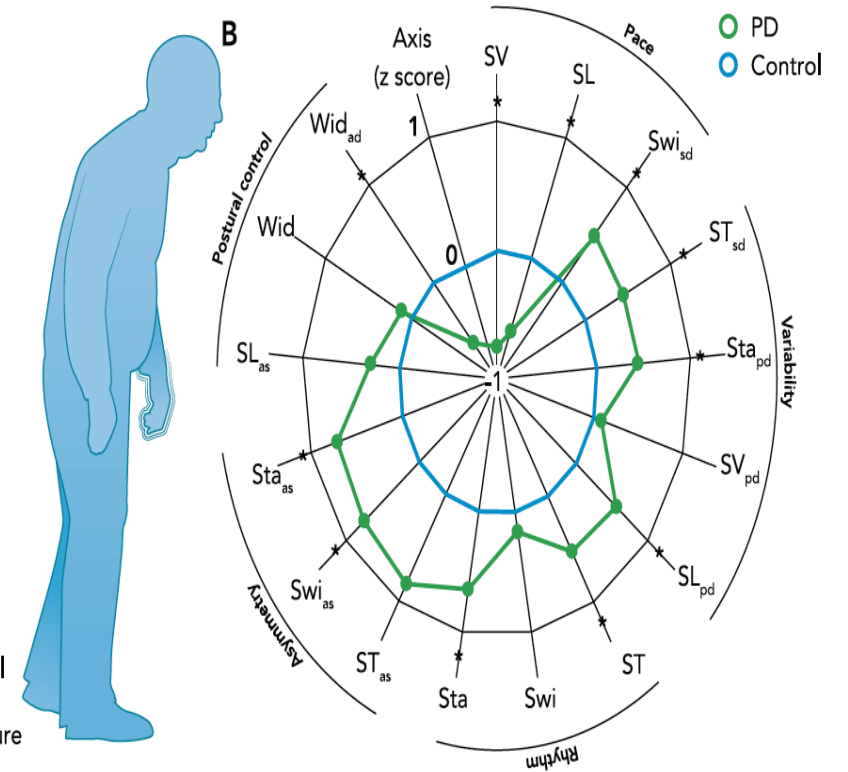
Increased variability and asymmetry

- Spatial
- Temporal

Postural instability

- Increased sway
- Poor reactive postural responses
- Poor anticipatory postural adjustments
- Altered coupling of posture and locomotion

B



Early stage Parkinson's disease

Mild to moderate Parkinson's disease

Advanced stage Parkinson's disease

Traditional Gait Assessment

Qualitative

- Traditional scales
- Semi-subjective
- Carried out by specialists who observe the quality of a patient's gait
- PROMs- patient subjective evaluation of his/her gait

Dynamic Gait Index (DGI)

Patient's full name: _____ Patient's age: _____
Patient's gender: _____ Date of assessment: _____

What you need:

- A 20-foot runway, should also be 10 inches wide; obstacle; 2 cones, an area with spots

1. Gait level surface

Instructions: Walk at your normal speed from here to the next mark (20 feet).
Grading: Mark the lowest category that applies.

Score	Level of function	Criteria
0	Severe impairment	Cannot walk 20 ft. without assistance, severe gait deviations, or instability.
1	Moderate impairment	Walks 20 ft., slow speed, abnormal gait pattern, evidence for instability.
2	Mild impairment	Walks 20 ft., uses assistive device, slower speed, mild gait deviations.
3	Normal	Walks 20 ft., no assistive device, good speed, no evidence of instability, normal gait pattern.

2. Change in gait speed

Instructions: Begin walking at your normal pace (for 5 ft.). When I tell you "GO," walk as fast as you can (for 5 ft.). When I tell you "SLOW," walk as slowly as you can (for 5 ft.).
Grading: Mark the lowest category that applies.

Score	Level of function	Criteria
0	Severe impairment	Cannot change speeds, or loses balance and has to reach for wall or be caught.
1	Moderate impairment	Makes only minor adjustments to walking speed or demonstrates a change in speed with significant gait deviations, or changes speed but has significant gait deviations, or changes speed but loses balance but is able to recover and continue walking.
2	Mild impairment	Able to change speed but demonstrates mild gait deviations, or no gait deviations but unable to achieve a significant change in walking, or asks an assistive device.
3	Normal	Able to smoothly change walking speed without loss of balance or gait deviation. Shows significant difference in walking speeds between normal, fast, and slow speeds.



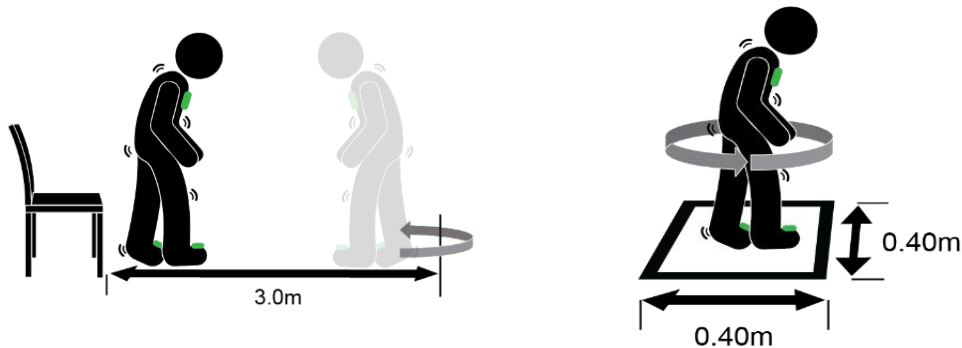
Quantitative

- Kinematics
- Kinetics
- Spatial -Temporal parameters
- Consistency



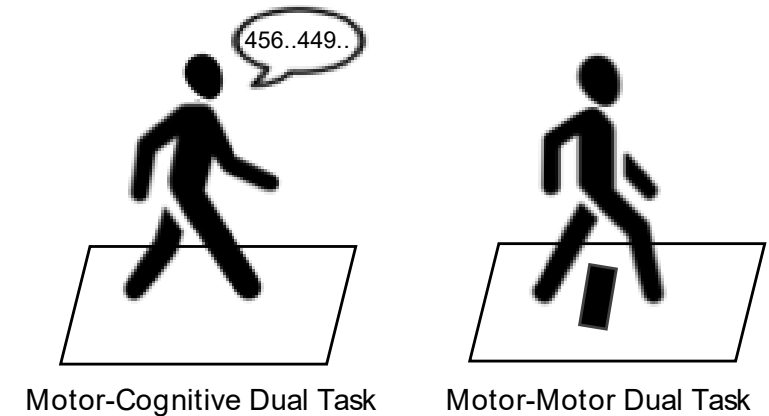
Challenging tasks

Turning is a significant mobility challenge that can lead to falls and reduced quality of life. Research indicates that turning performance is compromised in PD and can unmask FOG .



Understanding these dynamics is crucial for developing effective rehabilitation strategies to improve the quality of life for those affected by PD.

Dual task performance is also known as “concurrent performance” and involves the execution of a secondary task, which is the major focus of attention, and a primary (motor) task performed at the same time.

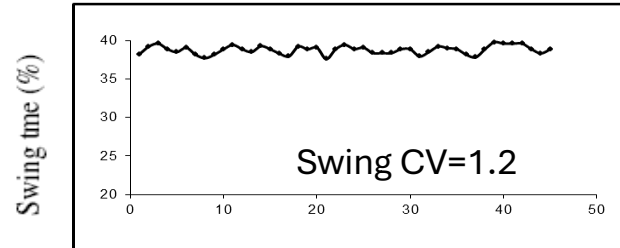


DT creates competition for attention and allocation of cognitive resources.

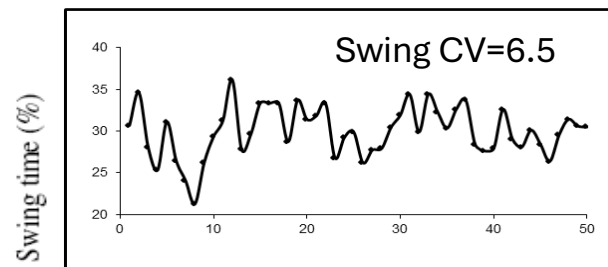
$$\frac{\text{dual task} - \text{single task}}{\text{single task} \times 100}$$

Dual task Serial subtracting

Control Subject



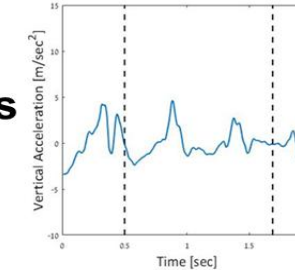
Patient with PD



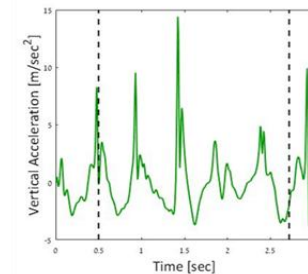
- It has been extensively demonstrated that gait disorders in people with PD are accentuated when they perform another task simultaneously.

Challenging task TUG

Control Subject

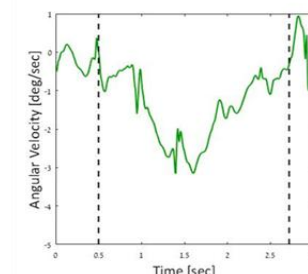
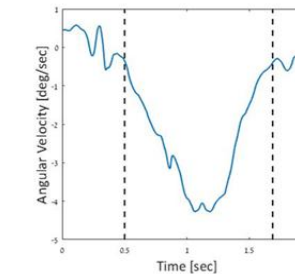


Patient with PD



Steps

Turn



Turn Duration: 1.179 [s]

Turn Duration: 2.21 [s]

REDUCED STEP LENGTH	(Morris, 1996; Bond, 2000; Rochester 2004; Galletly 2005)
REDUCED GAIT VELOCITY	(Bond, 2000; Rochester 2004; Galletly 2005; O'Shea, 2005)
INCREASED GAIT VARIABILITY	(Yogev, 2005; Plotnik 2009; Lord, 2011)
INCREASED RISK OF FALLING	(Yogev, 2005; Plotnik, 2011; Jacobs, 2014; Vanche 2015)

Does This...

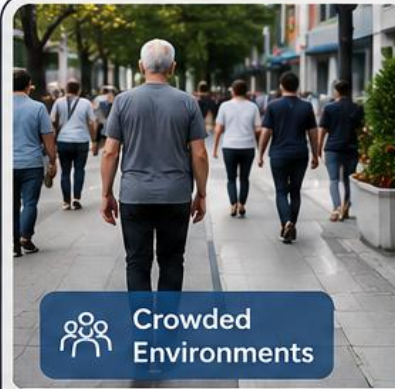
...truly reflect this?



In-Clinic Assessment



Brief • Controlled • Limited
Single environment • Observed



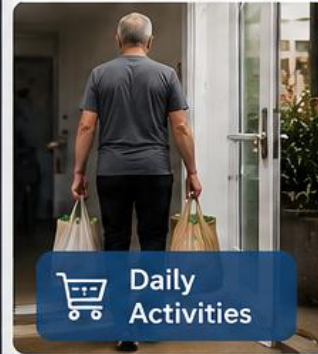
 **Crowded Environments**



 **Stairs & Transitions**



 **Uneven Surfaces**



 **Daily Activities**



 **Dual Tasking
(Cognitive Load)**



 **Fatigue & Symptom
Fluctuations**

Real-World Mobility

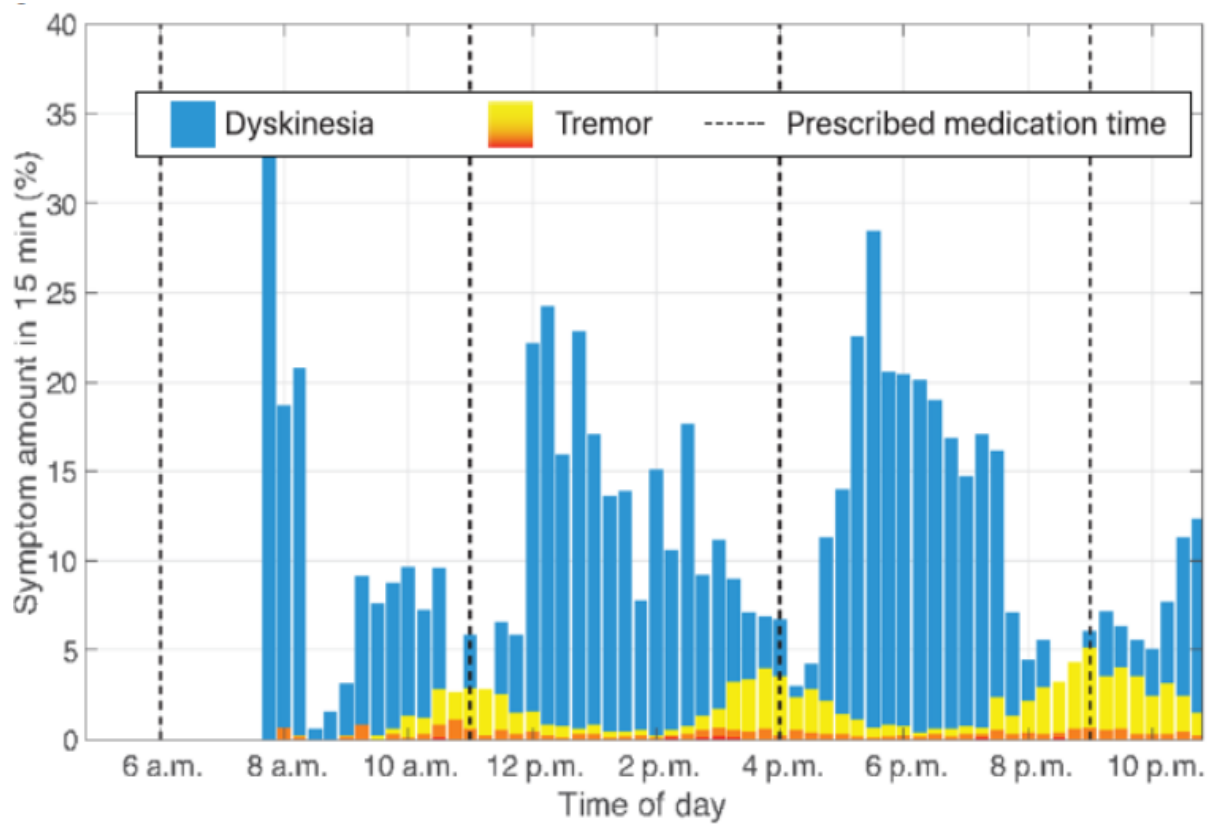
Variable • Unscripted • Unobserved • All Day, Every Day



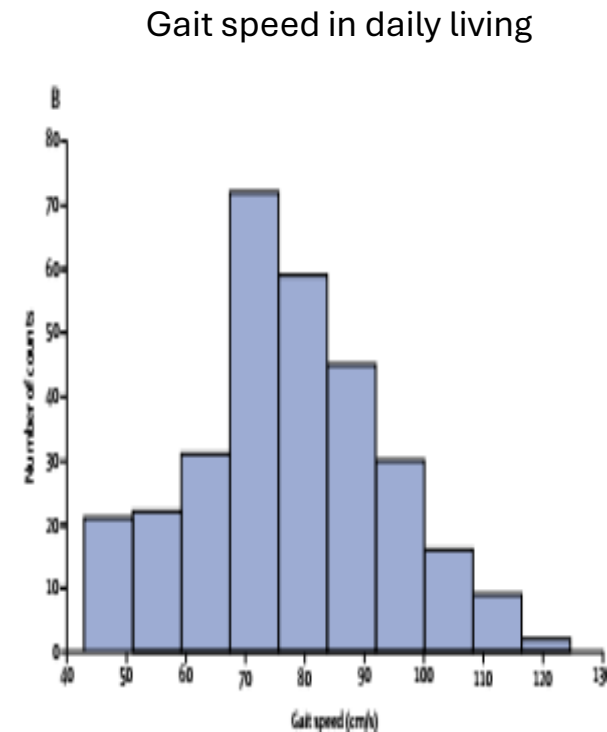
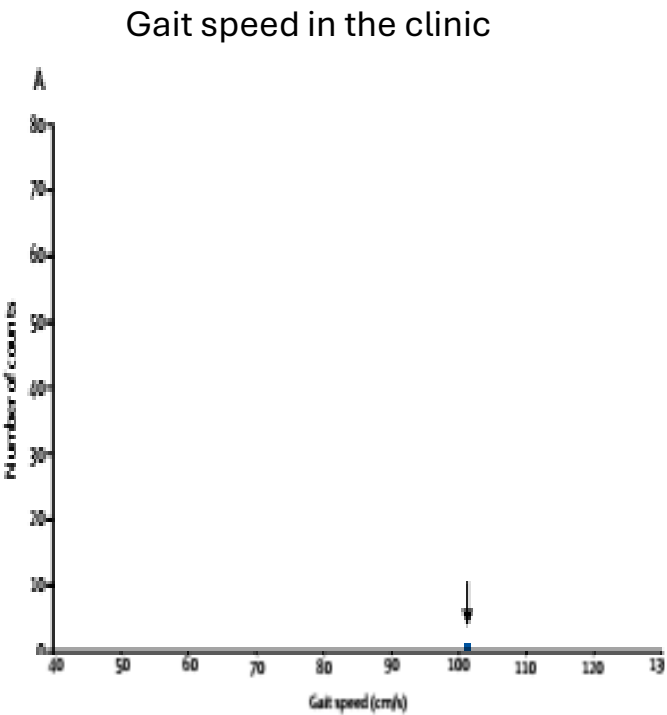
Does performance during a brief clinical assessment truly reflect mobility in **everyday life**?



Reflects the entire day cycle: Symptoms and function fluctuations

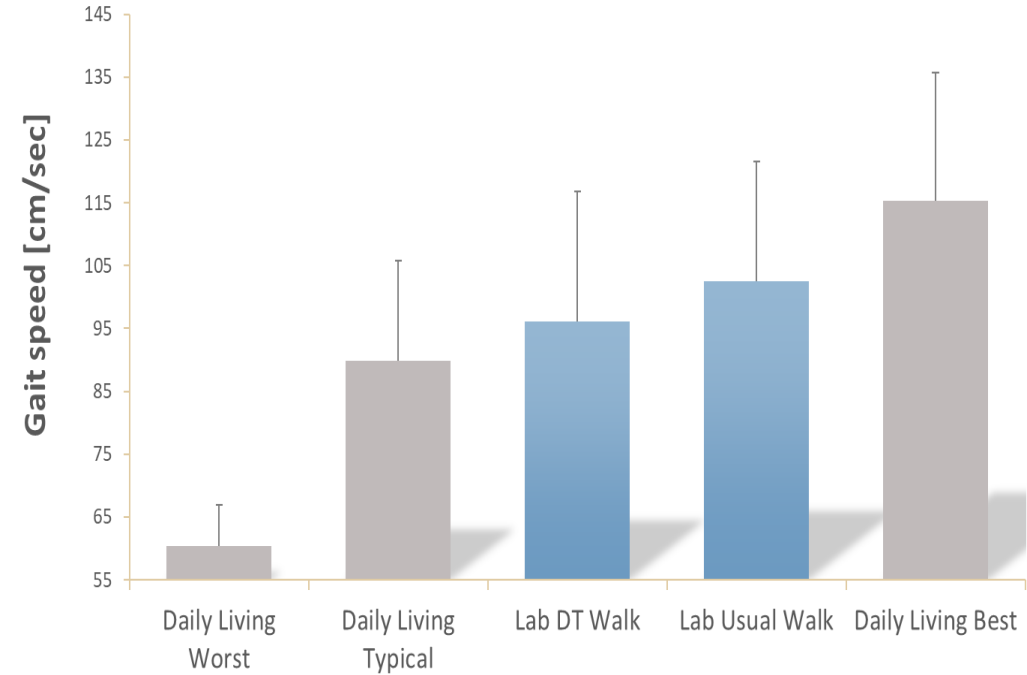
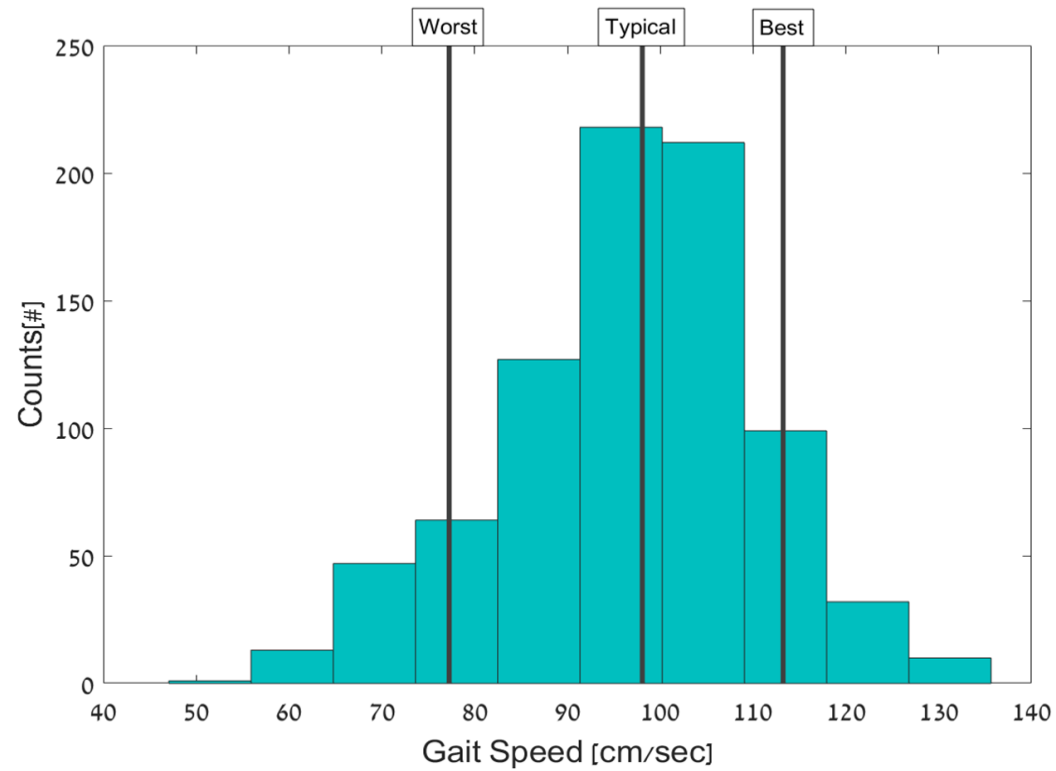


Powers et al 2021

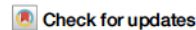


Warmerdam et al, 2020

Gait speed at home is slower than the most challenging assessment in the clinic



A systematic review of real-world gait-related digital mobility outcomes in Parkinson's disease



Cameron Kirk¹, Emma Packer¹, Ashley Polhemus², Mhairi K. MacLean³, Harry Bailey¹, Felix Kluge⁴, Heiko Gaßner^{5,6}, Lynn Rochester^{1,7,8,9}, Silvia Del Din^{1,7,9} & Alison J. Yarnall^{1,7,8,9} ✉

Gait outcomes



Pace
(speed, step length)



Rhythm
(step/stride time)



Variability
(step-to-step consistency)

1-14 days of
passive monitoring



KEY FINDINGS FROM 27 STUDIES (21 OUTCOMES)



PD walks slower
(lower speed,
shorter step length)



Longer step/
stride times



Greater gait
variability



Real-world gait
is generally worse
than lab-based gait



Findings for falls,
freezing of gait and
fatigue are inconsistent

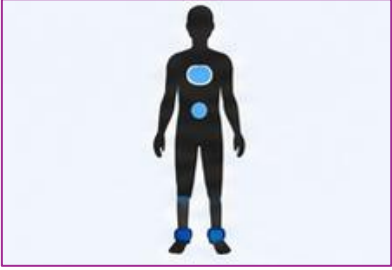
Pro's

- Consistently detected motor impairments in PD compared to controls
- Complement clinical assessment
- Potential digital biomarker

Major challenges

- Different sensors
- Different wear location
- Different recording duration
- Different walking bouts definitions

Current challenges in digital mobility



Sensor(s) placement

Different body location and # of sensors
Different hardware



Inconsistent activity classification

Different labels and definitions
(gait bouts, turns)



Different algorithms and no shared outcome standards

Similar constructs computed differently (gait speed, stride length, etc..)



No harmonized reporting

Sensors/wear protocol/walking bouts/outcomes/clinical descriptors



Lack of standardization = heterogeneity, poor comparability across studies, difficulty in acceptance



Limitations of existing literature

- No guidelines on a minimum protocol to obtain valid gait measures in people with PD,
- Protocols to assess gait in a quantitative way are extremely varied, their design is depending on available instrumentation, environmental constraints, and original hypotheses to test.
- The lack of standardization in protocols and reported gait measures is impeding data aggregation across centers and contributes to heterogeneity in the results, thus limiting the adoption of gait outcomes in clinical trials.

A framework to standardize gait study protocols in Parkinson's disease

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2025, Vol. 15(1) 129–139
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Sage | IOS Press

Martina Mancini¹ , Jeffrey M Hausdorff^{2,3} , Elisa Pelosin^{4,5} , Paolo Bonato⁶ , Richard Camicioli⁷ , Terry D Ellis⁸, Jochen Klucken⁹ , Larry Gifford¹⁰ , Alfonso Fasano^{11,12,13}, Alice Nieuwboer¹⁴ , Catherine Kopil¹⁵ , Katharina Klapper¹⁵ , Leslie Kirsch¹⁵ , David T Dexter¹⁶ , Rosie Fuest¹⁷, Vicki Miller¹⁸ , Angelica Asis¹⁹, Martijn LTM Müller²⁰ , Diane Stephenson²⁰ and Anat Mirelman² 

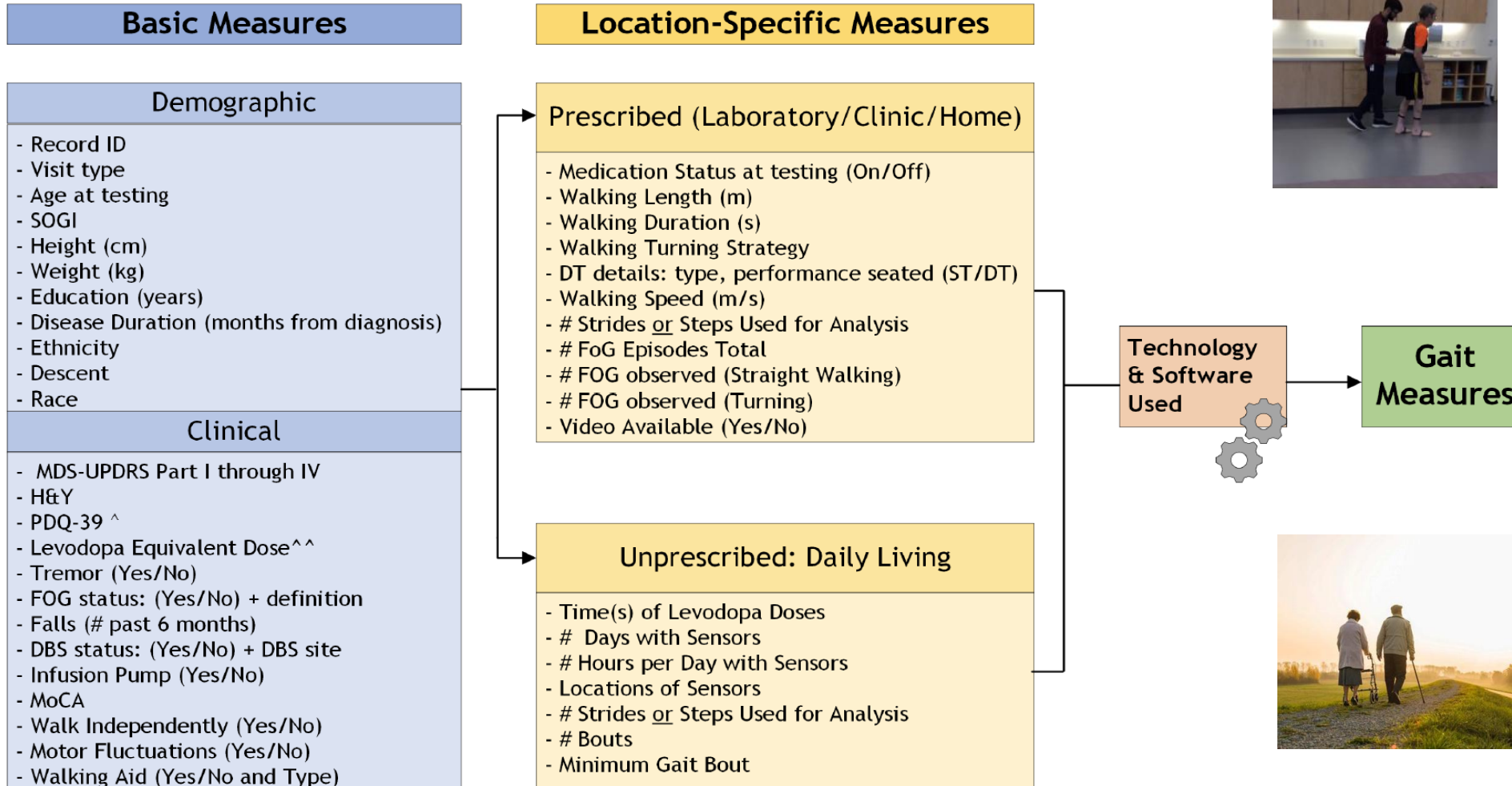


Objective: to recommend a minimum, common protocol for multicenter, natural history, and intervention studies to support the inclusion of specific gait measures for clinical trials in PD.

- Gait Advisors Leading Outcomes for Parkinson's (GALOP) committee (advisory committee for the MJFF)
- The Michael J. Fox Foundation for Parkinson's Research
- Parkinson's UK
- Cure Parkinson's
- Shake It Up Australia
- Parkinson Canada
- Critical Path Institute



Big picture recommendations:

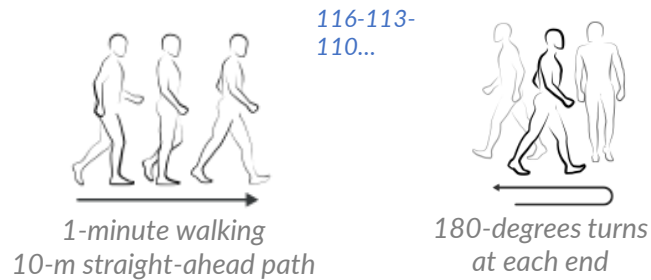


Framework: minimum protocol

Minimum in black -- Suggested in blue

Protocol, Prescribed assessment

- ✓ Walking at comfortable speed
 - One continuous gait task of at least 1 minute in duration
 - A path of 10-meters in length
 - 180 degrees turns at each end (ideally passing a line and turning back to the opposite end)



- ✓ Walking at comfortable speed with a cognitive dual-task
 - Choose among:
 - Arithmetic: N-back
 - Memory: Digit Span Forward
 - Language: Letter Fluency
- ✓ Walking as fast as possible

LAB SETTING

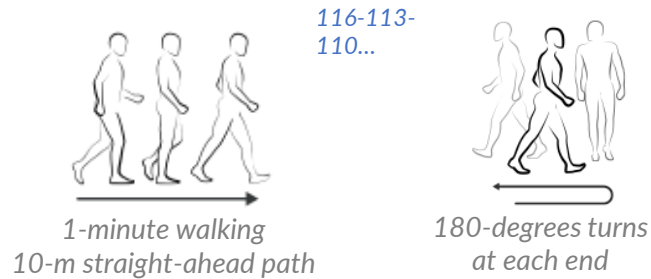


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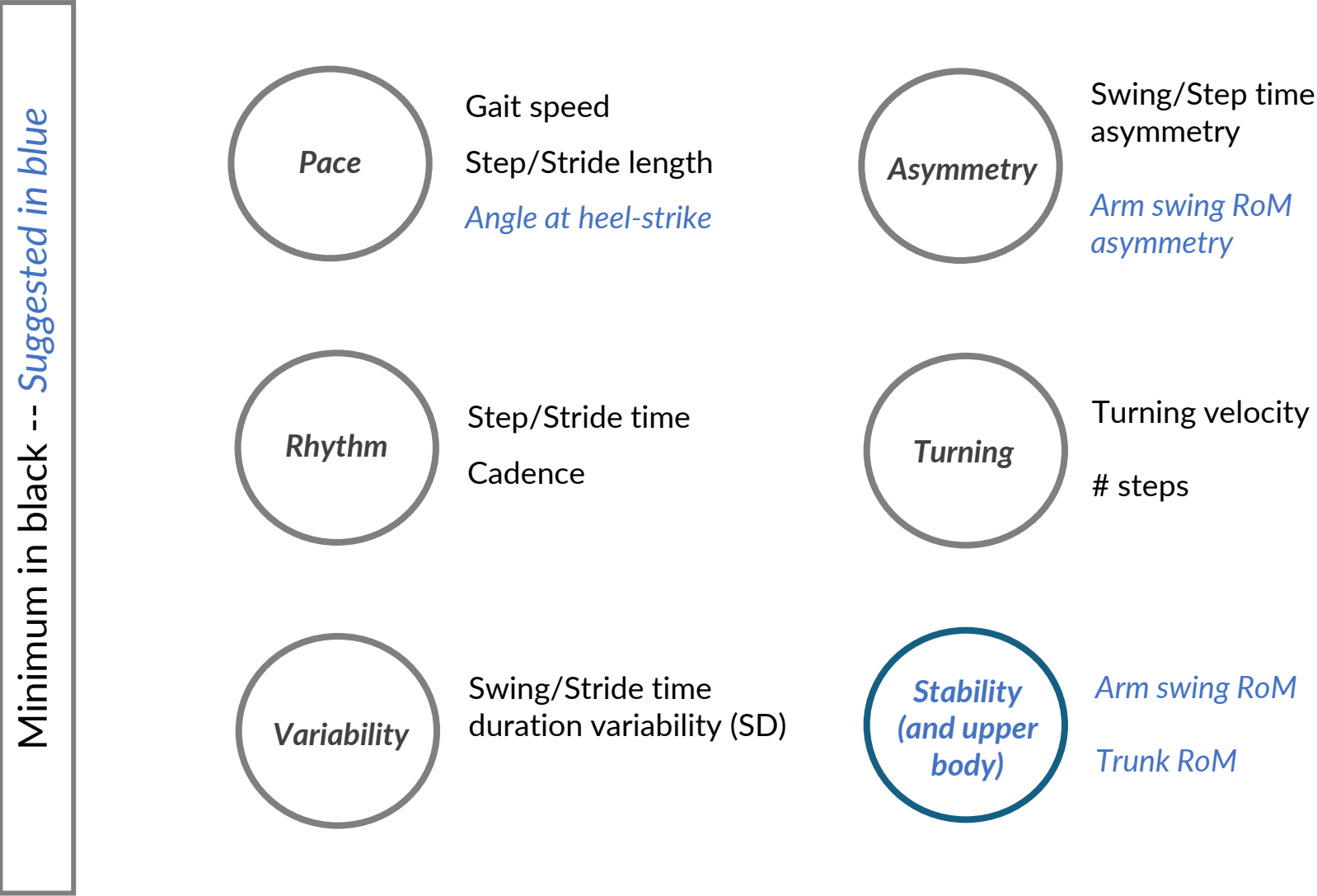
Protocol, unprescribed assessment

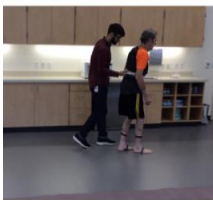
- ✓ Minimum of 3 days, best if 4 or more
- ✓ At least 8 hours/day, *best if 24/7*

DAILY LIFE SETTING

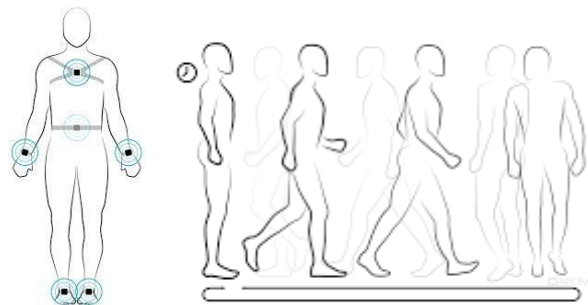


Framework: minimum set of gait measures





Which gait protocol for early vs moderate PD?



- *3 gait conditions!*
- *N=41 people with de-novo, untreated PD + 25 healthy controls*
- *N=134 people with moderate PD + 80 healthy controls*

**Normal
Walk ST**



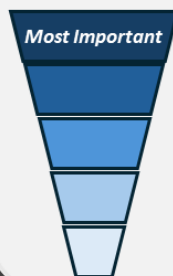
**Normal
Walk DT**



Fast Walk



de-novo PD vs HC

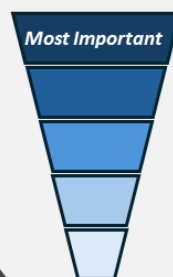


Arm Range SD
Gait Speed SD
Stride Length
Arm Range
Toe Off SD

Trunk Coronal SD
Arm Range
Trunk Transverse
Trunk Transverse SD
Trunk Coronal

Arm Range
Trunk Coronal
Toe Off SD
Stance Time SD
Double Support SD

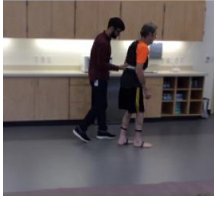
moderate PD vs HC



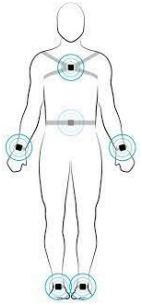
Turn Velocity
Arm Range
Stride Length
Foot Strike
Trunk Transverse SD

Turn Velocity
Foot Strike
Trunk Transverse SD
Arm Range
Stride Length

Turn Velocity
Arm Range
Terminal Double Support
Foot Strike
Trunk Transverse SD



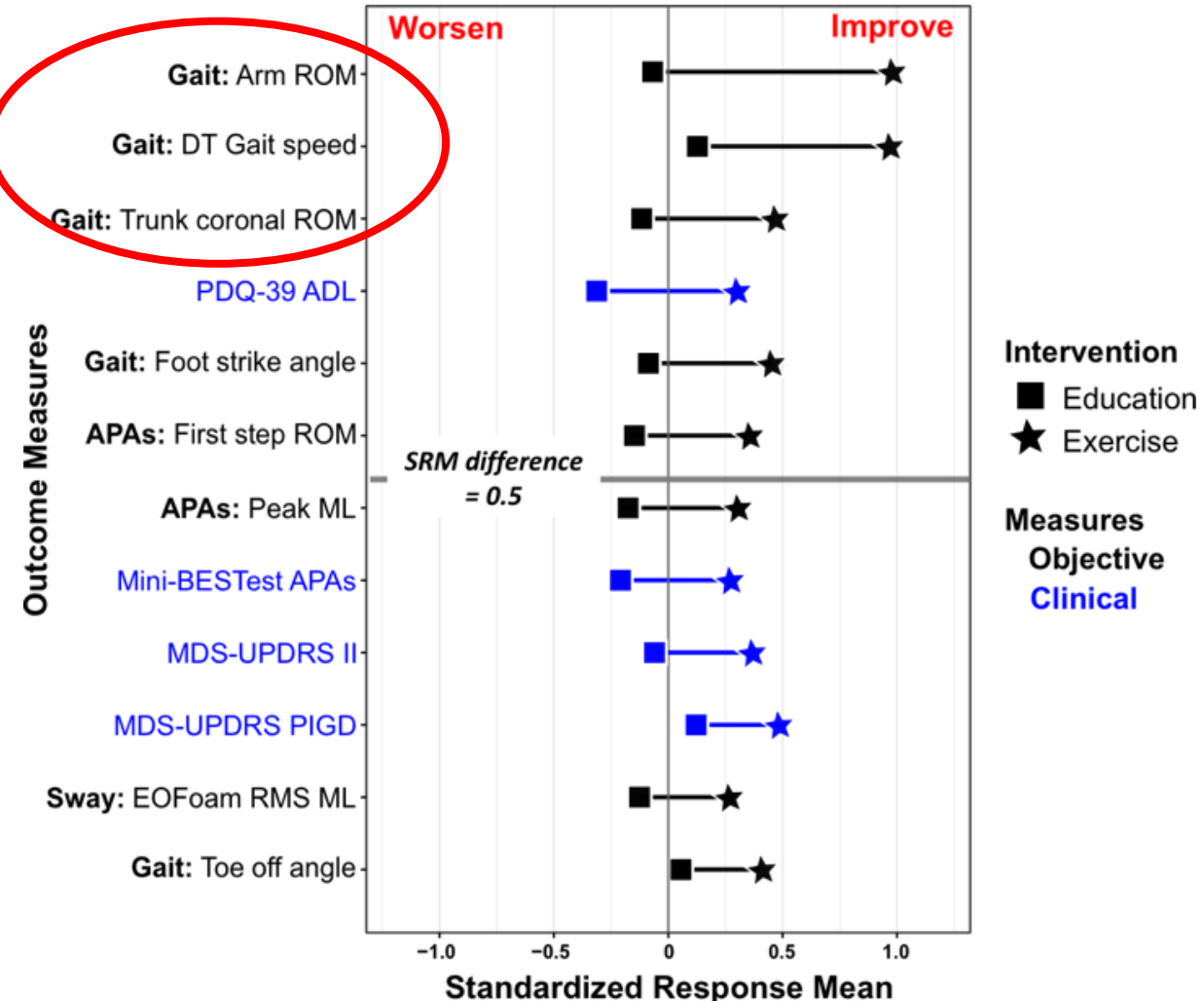
Which gait measures for response to exercise/rehabilitation?



- *ST+DT gait*
- *86 people with PD, tested Off med*

Randomized, controlled trial

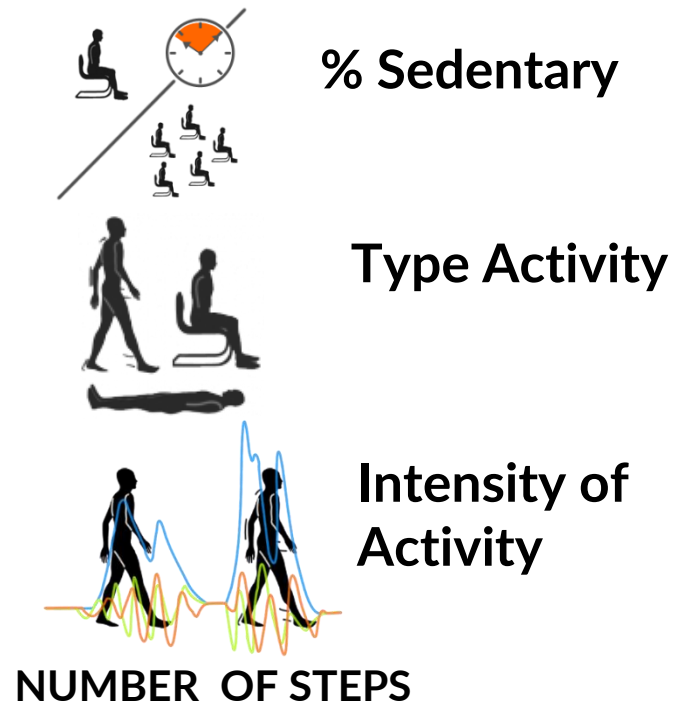
6 wks of ABC-C (Agility Boot Camp with cognitive challenge)
6wks of education



Unsupervised monitoring of mobility during daily life

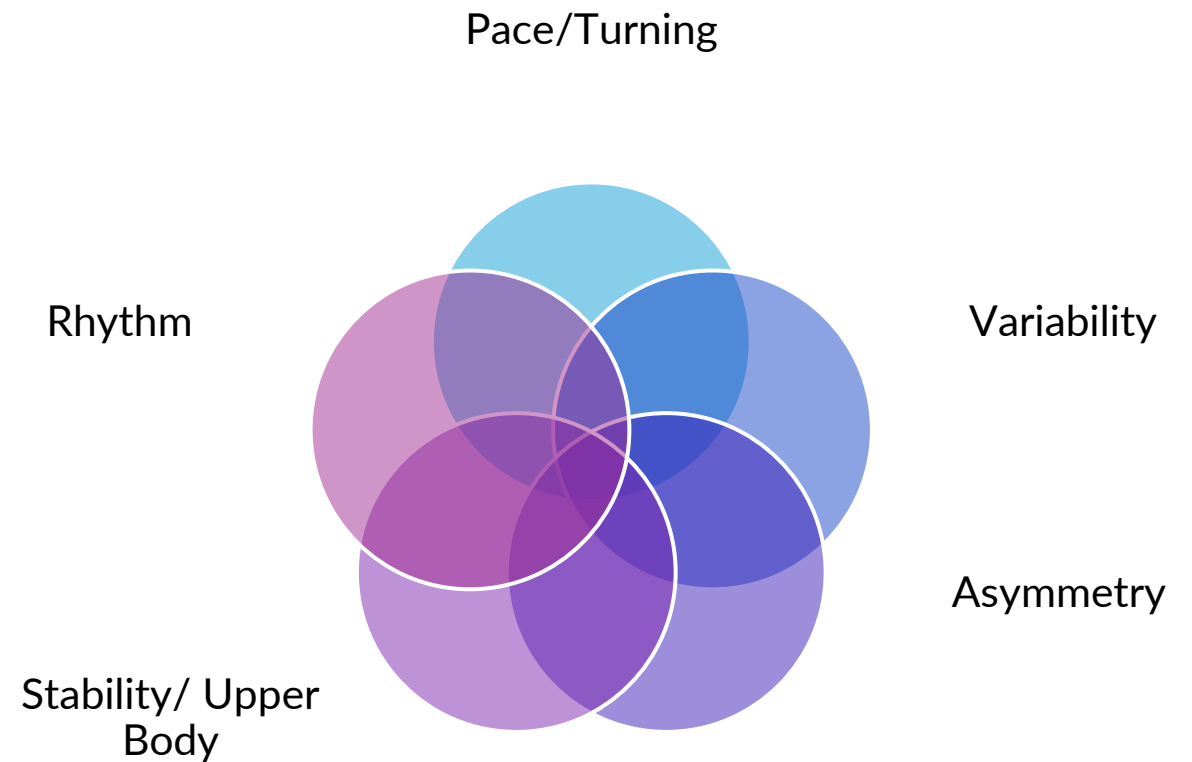
QUANTITY

How much a person is walking/turning



QUALITY

How a person is walking/turning

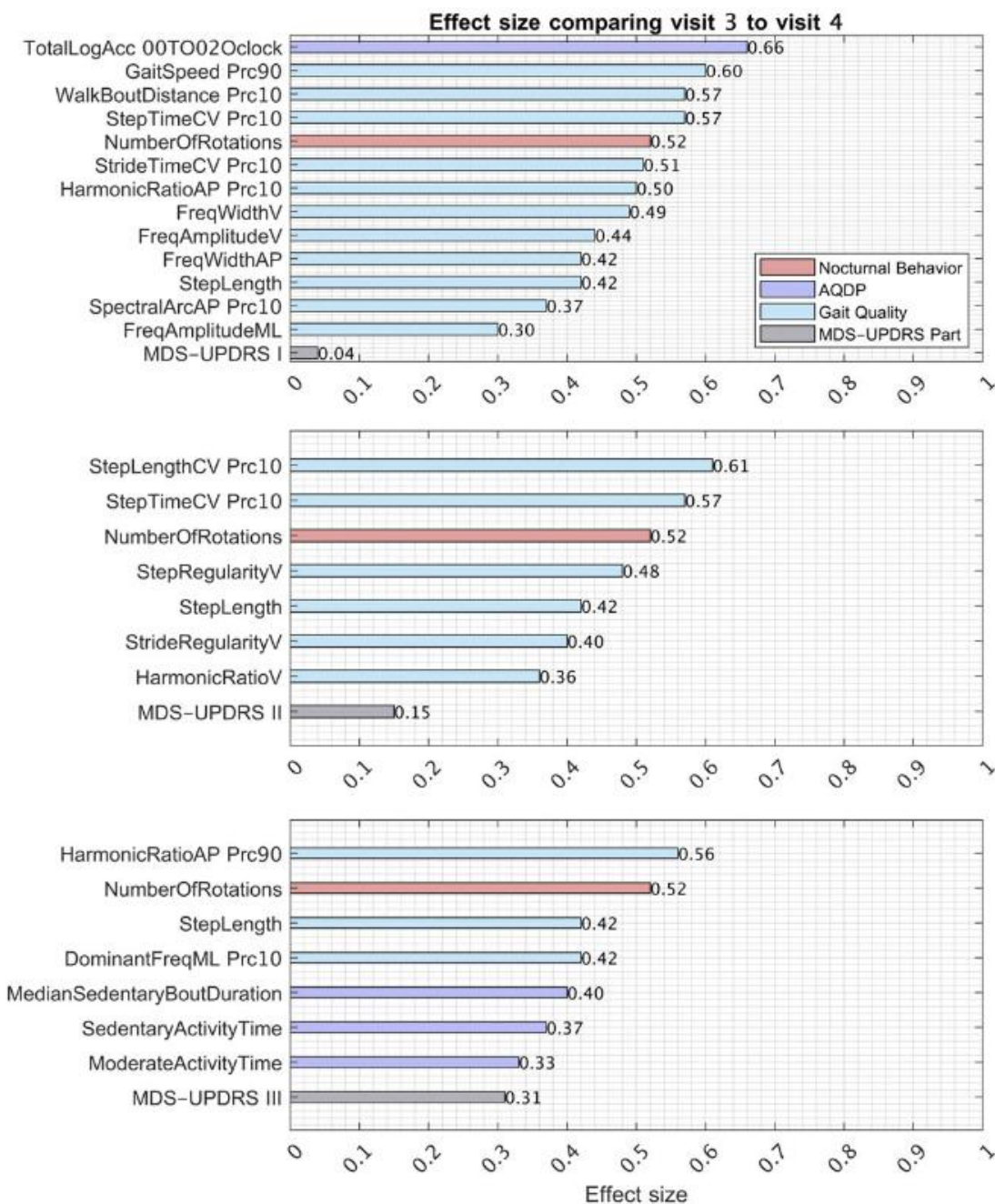


Digital Mobility Measures: A Window into Real-World Severity and Progression of Parkinson's Disease

Anat Mirelman, PhD,^{1,2*} Jana Volkov, MSc,¹ Amit Salomon, MSc,¹ Eran Gazit, MSc,¹ Alice Nieuwboer, PhD,³ Lynn Rochester, PhD,^{4,5} Silvia Del Din, PhD,^{4,5} Laura Avanzino, MD, PhD,^{6,7} Elisa Pelosin, PhD,^{6,8} Bastiaan R. Bloem, MD,⁹ Ugo Della Croce, PhD,¹⁰ Andrea Cereatti, PhD,¹¹ Avner Thaler, MD, PhD,^{1,2} Daniel Roggen, PhD,¹² Claudia Mazza, PhD,¹² Julia Shirvan, MD,¹² Jesse M. Cedarbaum, MD,^{13,14} Nir Giladi, MD,^{1,2} and Jeffrey M. Hausdorff, PhD^{1,2,15,16}

Effect sizes for Daily Life Gait Outcomes in PD Exceed UPDRS I, II, III

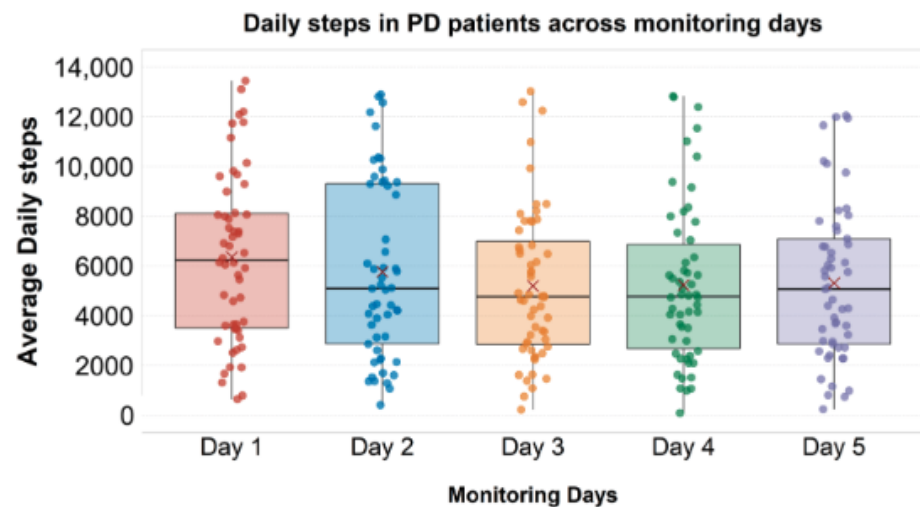
- N=587 PD and 68 controls at 6 sites for cross-sectional portion, 33 for longitudinal monitoring
- Visits every 12 months
- 301 Gait measures and 106 Activity measures





Daily-life gait: how many hours and days?

Commercial smartwatch



4 days for reliable step counts

Research grade sensor and ad-hoc algorithm

	Wear time	Number of days	Number of weekend days
Walking activity - Volume			
Walking duration	>13h	≥3	0
Number of steps	>13h	≥4	0
Number of turns	>12h	≥2	0
Walking activity - Pattern			
Number of WB	>13h	≥3	0
Number of WB > 10s	>13h	≥3	0
Number of WB > 30s	>13h	≥6	0
Number of WB > 60s	>13h	/	0
WB duration	>11h	≥4	0
Maximum WB duration	>14h	≥7	0
WB duration variability between all WB	>12h	/	0
Gait - Pace			
Walking speed in shorter (10-30s) WB	>12h	≥2	0
Walking speed in longer (>30s) WB	>12h	≥3	0
Maximum walking speed in WB > 10 s	>12h	≥2	0
Maximum walking speed in longer (>30s) WB	>12h	≥2	0
Stride length in shorter (10-30s) WB	>13h	≥1	0
Stride length in longer (>30s) WB	>12h	≥2	0
Gait - Rhythm			
Cadence in all WB	>11h	≥1	0
Cadence in longer (>30s) WB	>8h	≥3	0
Maximum cadence in longer (>30s) WB	>8h	≥3	0
Stride duration in all WB	>11h	≥3	0
Stride duration in longer (>30s) WB	>11h	≥3	0
Gait - Bout-to-bout variability			
Walking speed variability between longer (>30s) WB	None	/	0
Stride length variability between longer (>30s) WB	>12h	/	0
Cadence variability between all WB	None	≥2	0
Stride duration variability between all WB	>11h	≥7	0

Wear time and number of days upon gait measures
Minimum >12 h and ≥4 days

Take home messages

- Your protocol or equipment does not have to be complicated.
- Use consistent and standardized measures that have been validated.
- For good validity: use a path of at least 10 meters and continuously for at least 1-minute. Single-task at comfortable speed is minimum recommended, even more so if you want to measure variability of gait.
- Upper body measures of gait are important, particularly in early PD.
- Consider adding a dual-task if you work with people with moderate PD and turns are important!
- Don't be afraid of technology, it can help you gain insights into daily living
- Aim for a minimum of 3-4 days, best is 7 for monitoring in daily life!

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Thank you for your attention

