



Current clinical applications of motion capture in movement disorders

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Disclosures

JL McKay, PhD MSCR
Biocircuit Technologies

SA Factor, DO
Acadia, Adamas, Biogen,
Blackwell Futura, Demos,
Ipsen, Jazz, Sunovion,
Teva, Uptodate, US World
Meds, Lundbeck,
Medtronic, Neurocrine,
Prexton, Vaccinex, Voyager

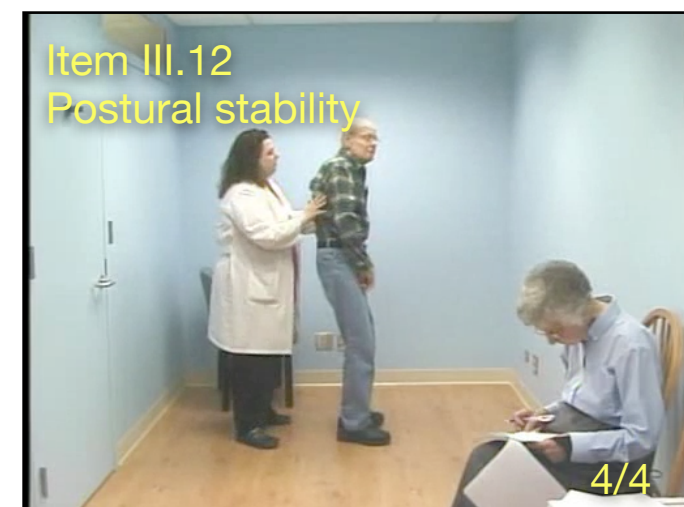
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Outline

1. Parkinson's disease symptoms are assessed clinically with a standardized motor exam ("MDS-UPDRS-III"), which has strengths and weaknesses
2. Examples of research studies employing markerless and traditional motion capture in conditions including PD
3. Examples of motion capture in clinical use in the Emory Movement Disorders Center
4. Progress toward quantification of Freezing of Gait in research and clinical settings
5. Closing remarks

Parkinson's disease symptoms are assessed clinically with a standardized motor exam ("MDS-UPDRS-III")



Parkinson's disease symptoms are assessed clinically with a standardized motor exam (“MDS-UPDRS-III”)

- The MDS-UPDRS-III is reliable and repeatable when scored by a specially-trained movement disorders specialist.
- Each item is scored 0, 1, 2, 3, or 4 in escalating order of severity.
- The total score is calculated. Subdomains and phenotypes (e.g., tremor vs. postural problems) can be calculated.¹
- Similar rating scales are used in other disorders. (TETRAS, essential tremor; EDSS, multiple sclerosis; TWSTRS, cervical dystonia)

Parkinson's disease symptoms are assessed clinically with a standardized motor exam ("MDS-UPDRS-III")

3.5 HAND MOVEMENTS

Instructions to examiner: Test each hand separately. Demonstrate the task, but do not continue to perform the task while the patient is being tested. Instruct the patient to make a tight fist with the arm bent at the elbow so that the palm faces the examiner. Have the patient open the hand 10 times as fully AND as quickly as possible. If the patient fails to make a tight fist or to open the hand fully, remind him/her to do so. Rate each side separately, evaluating speed, amplitude, hesitations, halts, and decrementing amplitude.

- | | |
|--------------|---|
| 0: Normal: | No problems. |
| 1: Slight: | Any of the following: a) the regular rhythm is broken with one or two interruptions or hesitations of the movement; b) slight slowing; c) the amplitude decrements near the end of the task. |
| 2: Mild: | Any of the following: a) 3 to 5 interruptions during the movements; b) mild slowing; c) the amplitude decrements midway in the task. |
| 3: Moderate: | Any of the following: a) more than 5 interruptions during the movement or at least one longer arrest (freeze) in ongoing movement; b) moderate slowing; c) the amplitude decrements starting after the 1st open-and-close sequence. |
| 4: Severe: | Cannot or can only barely perform the task because of slowing, interruptions, or decrements. |

3.11 FREEZING OF GAIT

Instructions to examiner: While assessing gait, also assess for the presence of any gait freezing episodes. Observe for start hesitation and stuttering movements especially when turning and reaching the end of the task. To the extent that safety permits, patients may NOT use sensory tricks during the assessment.

- | | |
|--------------|---|
| 0: Normal: | No freezing. |
| 1: Slight: | Freezes on starting, turning, or walking through doorway with a single halt during any of these events, but then continues smoothly without freezing during straight walking. |
| 2: Mild: | Freezes on starting, turning, or walking through doorway with more than one halt during any of these activities, but continues smoothly without freezing during straight walking. |
| 3: Moderate: | Freezes once during straight walking. |
| 4: Severe: | Freezes multiple times during straight walking. |

Parkinson's disease symptoms are assessed clinically with a standardized motor exam (“MDS-UPDRS-III”)

- Weaknesses (my opinion):
 - Many patients do not have access to neurologists with appropriate training
 - Limited specificity in diagnostic settings, in which it is sometimes used
 - Does not quantify motor behaviors involving multiple body parts, that occur in cases like psychogenic tremor

Many disorders (like PSP) can present with parkinsonian motor features on MDS-UPDRS-III

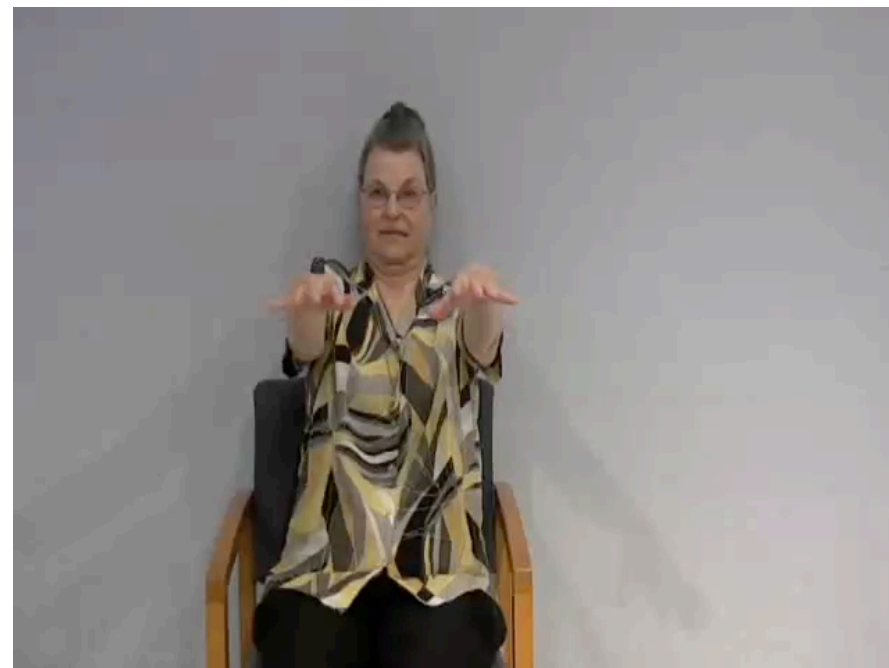


- Male, 71 years old
- 2018 ICD-10-CM Diagnosis Code G20, *Parkinson's disease*
- Duration 10 years
- 450 mg levodopa, 1 mg rasagiline daily
- Total OFF motor score 48/132 (SA Factor, DO)
- 6 months later: altered diagnosis to G23.1, *Progressive supranuclear ophthalmoplegia* (PSP; tau accumulation vs. alpha-synuclein accumulation)
- ≈30% PSP cases confirmed post mortem were never correctly diagnosed ante mortem¹

MDS-UPDRS-III does not quantify motor behaviors involving multiple body parts



- Examples of psychogenic tremor¹
- Video 1: distractibility with motor tasks. The tremor in the hands decreases in amplitude when the patient flexes and extends the opposite hand. (An increase is probably expected in PD.)



- Video 5: entrainability. The patient has a slow truncal tremor that is irregular. When she opens and closes her hands, the truncal tremor entrains to the frequency of the hand movements, increasing and decreasing in frequency.

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Motion capture has been used previously to quantify gait outcomes after therapies like DBS

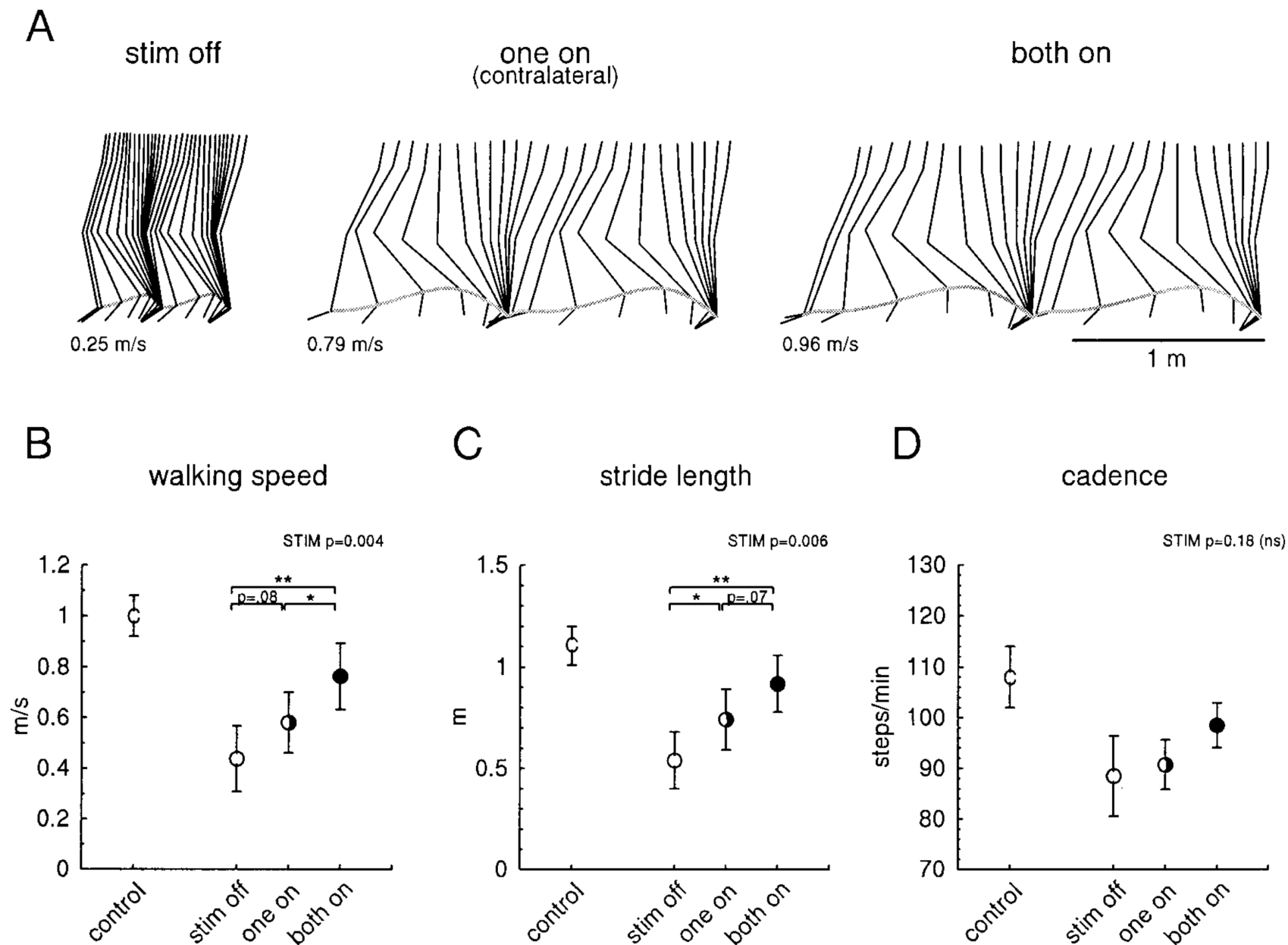
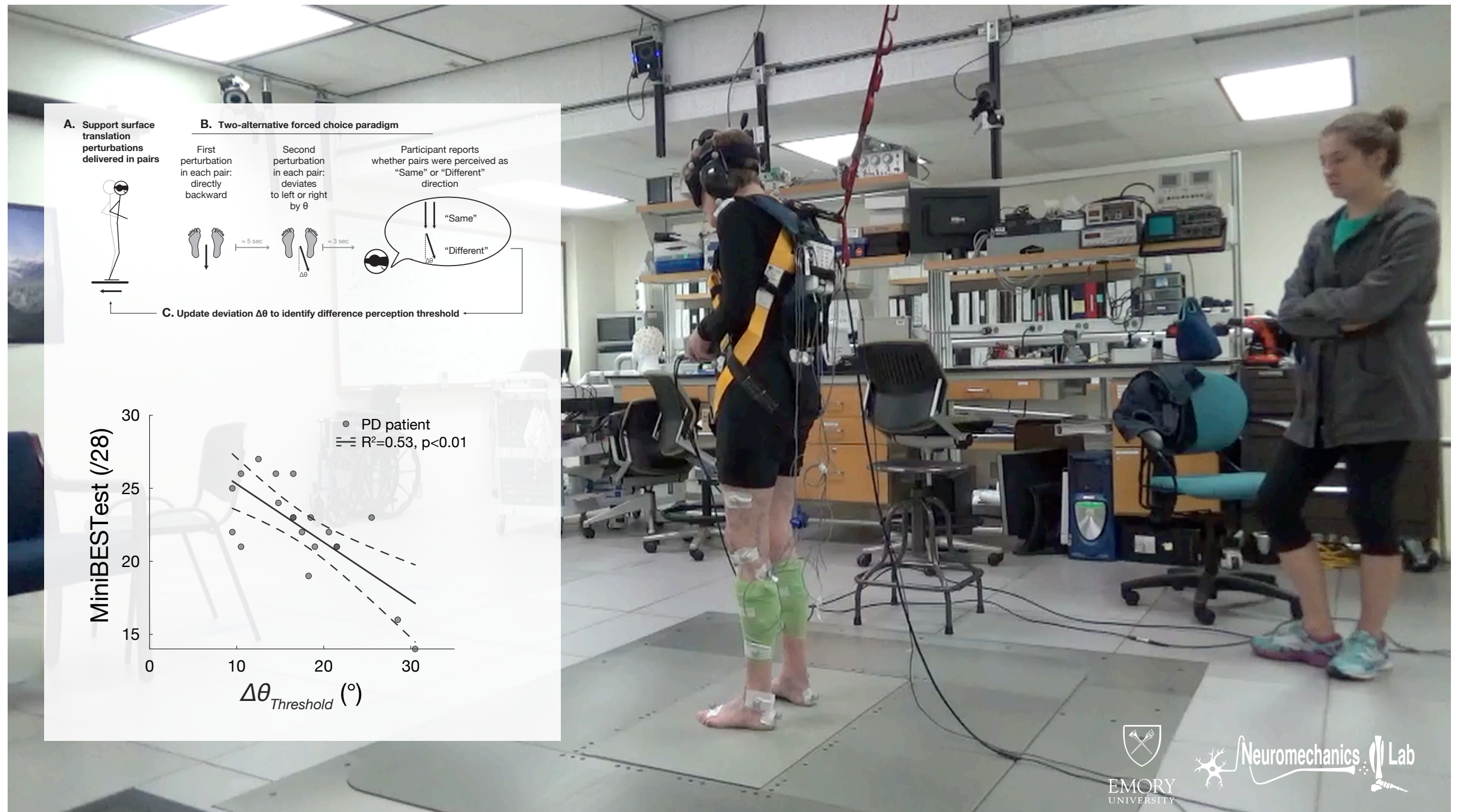


FIG. 2. **A:** Stick figure drawings of an example subject (STN-1) walking with both stimulators off, the contralateral stimulator on, and both stimulators on. Each stick figure is drawn every 100 msec and consists of a foot, shank, thigh, and pelvis segment. Note that the foot segment is drawn between the fifth metatarsal head and the ankle joint, causing it to always appear in an angled position (plantar flexed). Bold grey lines track the position of the ankle joint. **B:** Walking speed for controls (C) and Parkinson's disease subjects. Open circles, both stimulators off; half-filled circles, one stimulator on; filled circles, both stimulators on. **C:** Stride length. **D:** Cadence. Post hoc comparisons: * $P \leq 0.05$; ** $P \leq 0.01$.

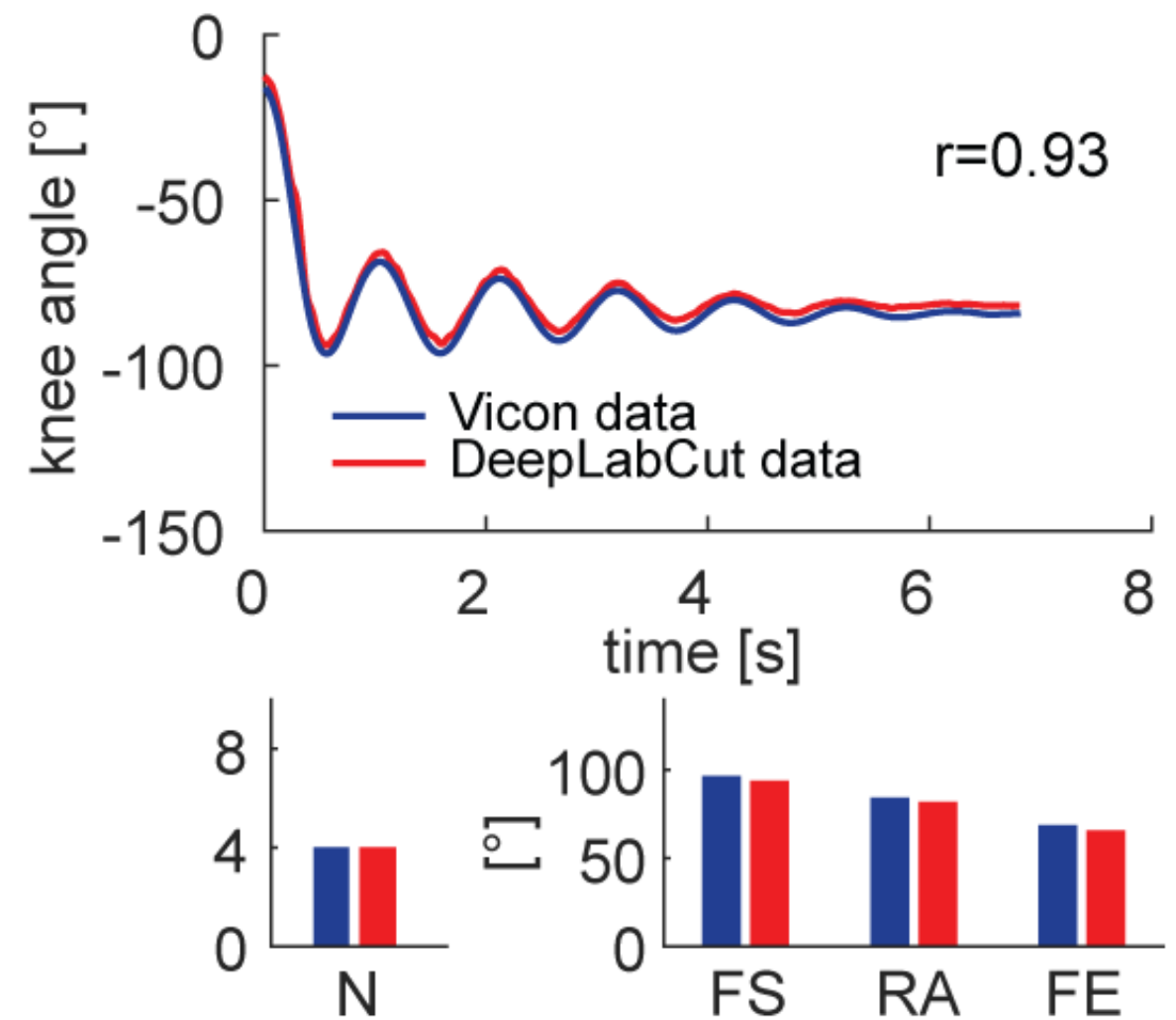
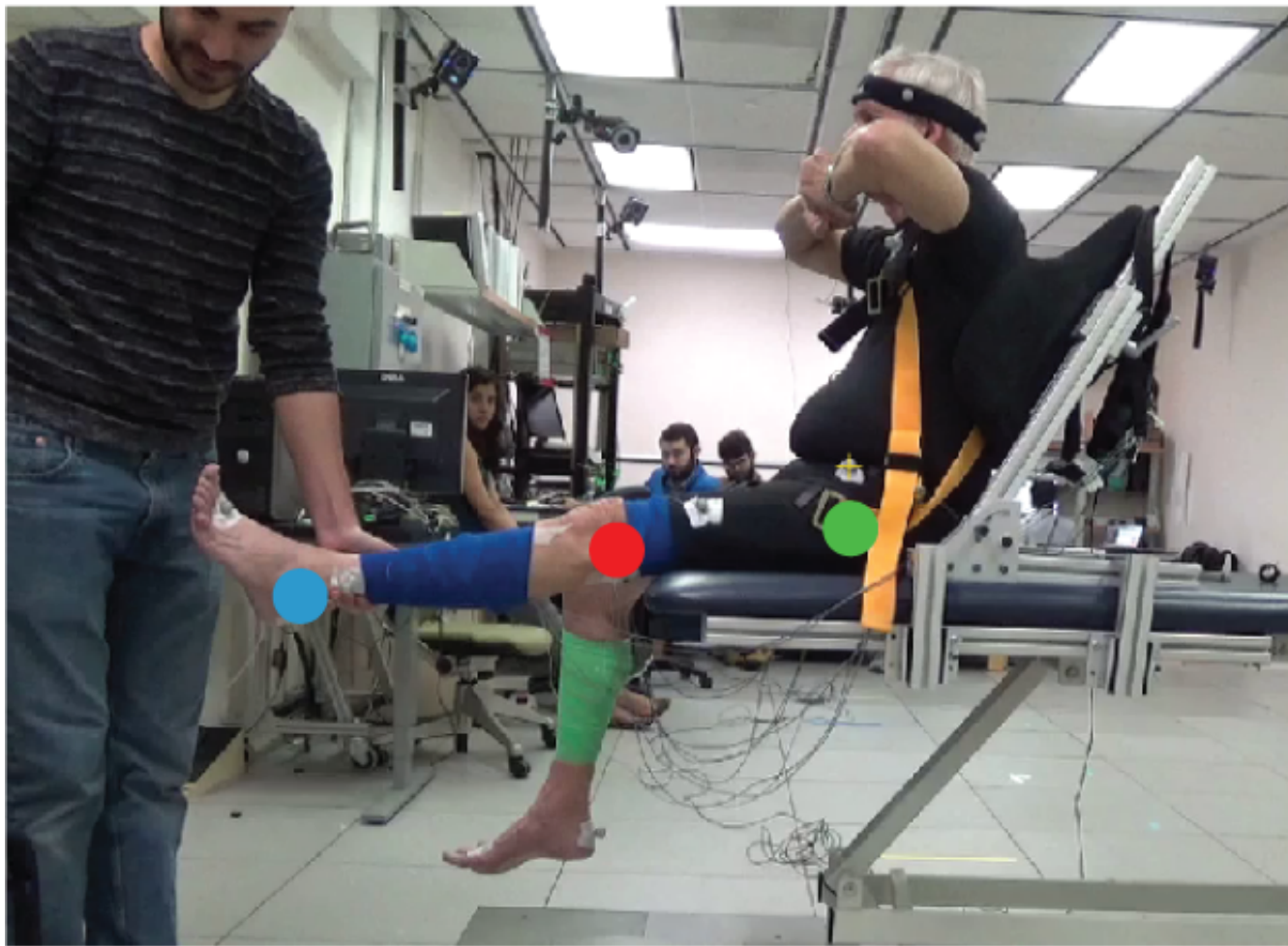
Perception of whole-body motion is impaired in PD – and associated with balance impairments



Markerless motion capture of MDS-UPDRS-III motor exam tasks



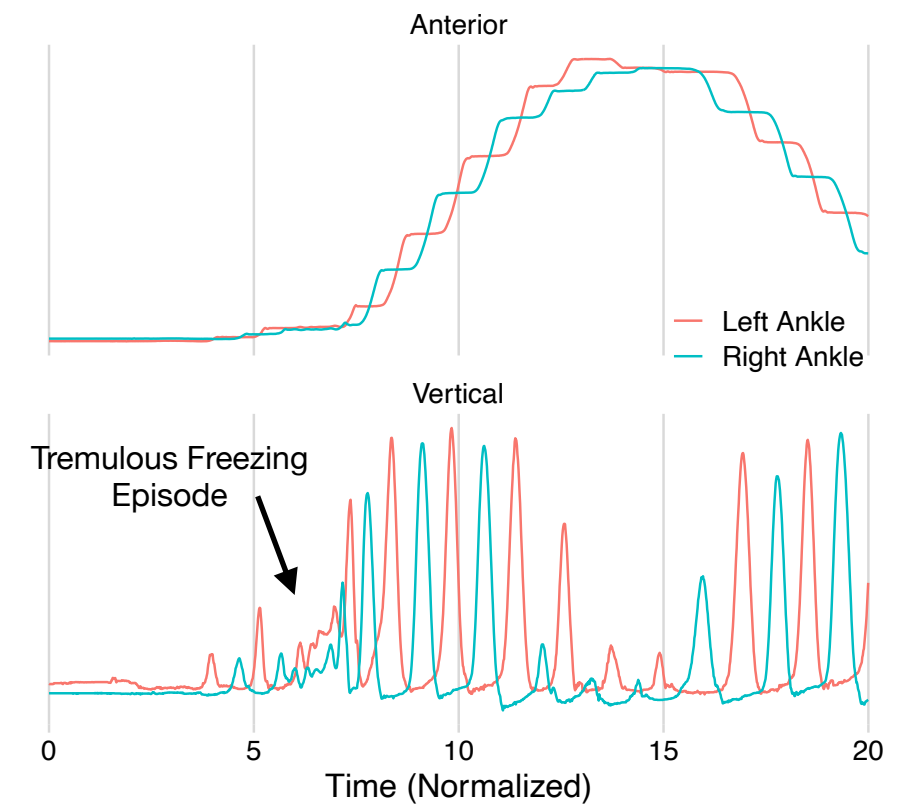
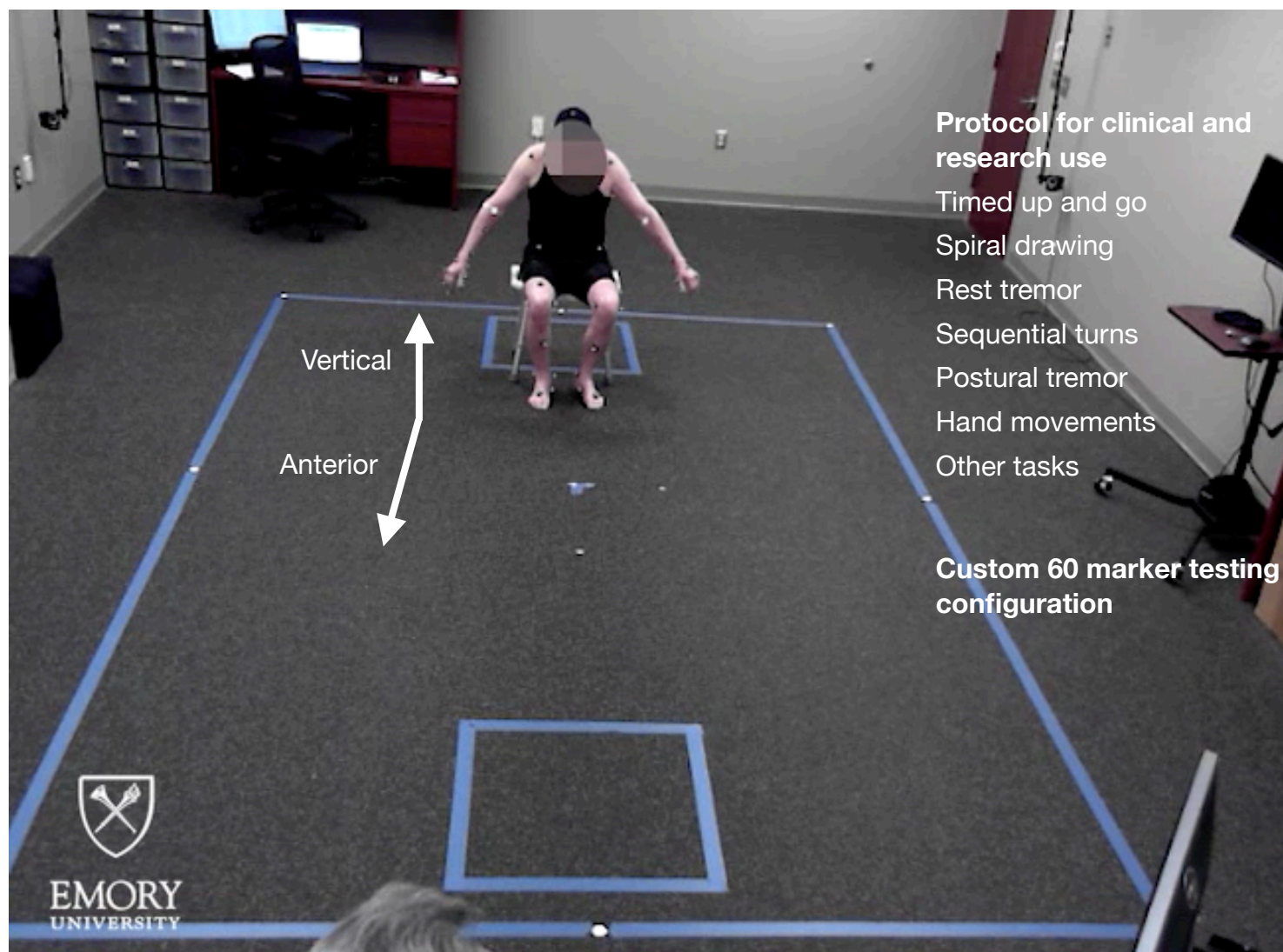
Comparison of kinematic outcome measures collected with and without markers



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Motion analysis laboratory for clinical and research use at Emory Movement Disorders Clinic



Ordering motion analysis for clinical use

- Common procedural terminology (CPT) codes
 - **CPT 96000:** Comprehensive computer-based motion analysis by video-taping & 3-D kinematics. \$333
 - **CPT 96004:** Physician review and interpretation of comprehensive motion analysis, dynamic plantar pressure, dynamic surface electromyography & dynamic fine wire electromyography, with written report. \$397
 - Comparable to CPT 70551: MRI w/o contrast. ≈\$700
- Common indications
 - Evaluation for DBS
 - Complex presentation

Clinic case: tremor amplitude evaluation prior to functional neurosurgery

Motion Analysis Report
The Emory Clinic, Inc
Department of Neurology at Executive Park
Movement Disorders Program
MOTION ANALYSIS LABORATORY

PATIENT NAME: **MARKER SET:** HH-60
DATE OF BIRTH: **ASSIST. DEVICE:** NONE
MEDICATION STATUS: LAST DOSE OF PD MEDS WAS 1 ½ HOURS PRIOR TO PROCEDURE.
REPORTING MD: CHRISTINE DOSS ESPER, MD
REQUESTING MD: CHRISTINE DOSS ESPER, MD

INDICATION: Parkinson's disease, pre-DBS evaluation

INTERPRETATION:

FINAL IMPRESSION: Abnormal. Parkinson's disease, as evidenced by a right hand rest>postural tremor in 9 of 11 tasks, in addition to a stooped posture with ambulation.
GAIT ANALYSIS: Abnormal. Gait Analysis revealed a normal forward velocity, step length, and cadence, in addition to an anterior tilt of the head and trunk.
ABNORMAL MOVEMENTS: Abnormal. Spectral Analysis of 3D marker displacements revealed a right hand rest > postural tremor in 9 of 11 motor assessments.

Gait Analysis revealed normal forward velocity, step length, stride length, and cadence. Initial double support time was moderately increased bilaterally (RIGHT 130.4%; LEFT 126.8%) and step width was diminished (61.3%). The remainder of the gait indices were within normal range including: total support time, swing phase, and single support time.

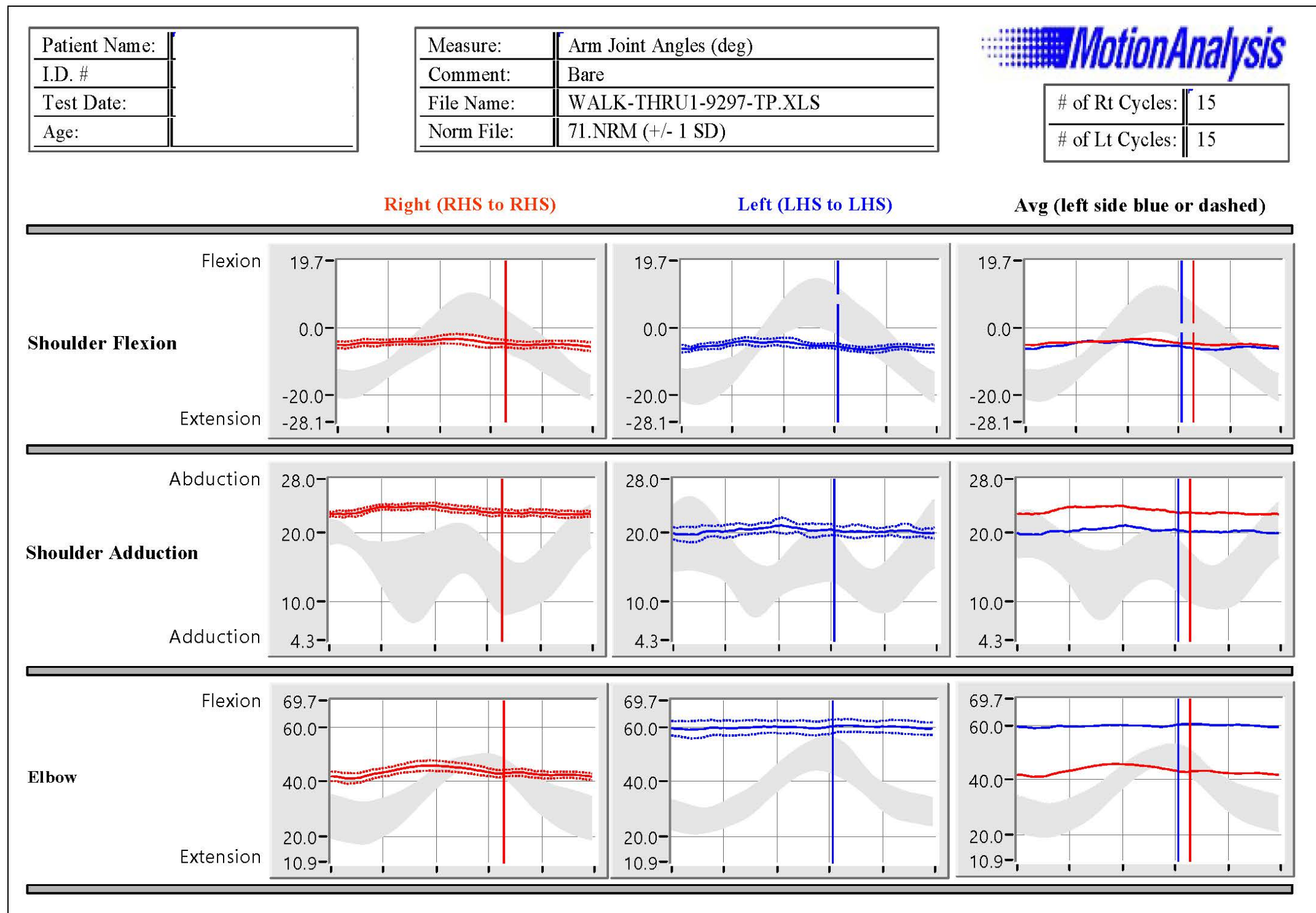
Analysis of 3D joint kinematics showed some external rotation of the HIPS and KNEES bilaterally, right > left, in addition to a mild internal rotation of the ANKLES bilaterally. With ambulation, he had an anterior tilt of the HEAD and TRUNK, with good arm-swing bilaterally, but diminished SHOULDER abduction on the right and shoulder adduction on the left. These results are non-specific but may be associated with prior injury, fatigue, caution, diminished effort, or Parkinson's disease.

Spectral Analysis of 3D marker displacements revealed a tremor in ONE or BOTH hands in 9 of 11 motor assessments. This included a 4.5Hz ± 0.35Hz mild-to-moderate amplitude RIGHT HAND rest tremor in 5 tasks and a 4.84Hz ± 0.5Hz mild-to-moderate RIGHT HAND postural tremor in 3 tasks. A 5 Hz slight amplitude left hand rest tremor was also present with the provocative maneuver of 3D spiral drawing with the right hand. There was no abnormal periodicity (i.e., tremor) at any of the 60 marker sites in ONE or BOTH in the following tasks: 3D pointing to a target with the right hand and walking.

TECHNICAL RESULTS:					
GAIT ANALYSIS:					
Spatiotemporal Indices:					
	RIGHT	NORMALS	LEFT	RT/Norm	LT/Norm
Step Length Avg (cm)	62.976	64.88	64.422	97.1%	99.3%
Standard Deviation	1.326	7.6	2.023		
Number of Steps	13	10	12		
Stride Length Avg (cm)	127.93	129.82	127.48	98.5%	98.2%
Standard Deviation	2.587	15.05	2.826		
Number of Strides	10	10	10		
Forward Velocity Avg (cm/s)	120.554	118.34	120.584	101.9%	101.9%
Standard Deviation	3.584	17.83	3.89		
Number of Strides	10	10	10		
Cadence Avg (steps/min)	112.562	109.46	113.152	102.8%	103.4%
Standard Deviation	2.633	8.52	1.938		
Number of Steps	10	10	10		
Total Support Time (%)	63.366	60.56	63.617	104.6%	105.0%
Standard Deviation	0.765	0.87	1.011		
Number of Strides	10	10	10		
Swing Phase (%)	36.634	39.44	36.383	92.9%	92.2%
Standard Deviation	0.765	0.87	1.011		
Number of Strides	10	10	10		
Initial Double Support Time (%)	13.733	10.53	13.347	130.4%	126.8%
Standard Deviation	0.804	0.83	0.864		
Number of Strides	10	10	10		
Single Support Time (%)	36.383	39.44	36.634	92.2%	92.9%
Standard Deviation	1.011	0.87	0.765		
Number of Strides	10	10	10		
Step Width (cm)	7.332	11.97	7.332	61.3%	61.3%
Standard Deviation	1.404	3.31	1.404		
Number of Trials	5	10	5		

ABNORMAL MOVEMENTS:								
StatTable-sit-fingtap1-TP								
Abnormality:	R Hand	R Dist Arm	R Prox Arm	Head	Shoulders	L Prox Arm	L Dist Arm	L Hand
Apraxia	-	-	-	-	-	-	-	-
Ataxia	-	-	-	-	-	-	-	-
Athetosis	-	-	-	-	-	-	-	-
Chorea	-	-	-	-	-	-	-	-
Clonus	-	-	-	-	-	-	-	-
Dyskinesia	-	-	-	-	-	-	-	-
Dystonia	-	-	-	-	-	-	-	-
Myoclonus	-	-	-	-	-	-	-	-
Tics	-	-	-	-	-	-	-	-
Tremor	+	-	-	-	-	-	-	-
Aphysiologic	-	-	-	-	-	-	-	-
Spectral Properties:								
Fc(PeakPower), Hz	4.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FcBand(HlfPwr),LoF	4.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FcBand(HlfPwr),HfF	5.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pc,(ΣPwr),[mm/s] ²	149908.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pc/TotalPower, %	41.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ac,(Pc ^{1/2} ,Veloc),mm/s	387.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Provocative Factors:								
Action-Dependent	-	-	-	-	-	-	-	-
Posture-Dependent	-	-	-	-	-	-	-	-
None ("Resting")	+	-	-	-	-	-	-	-

Clinic case: comparison of arm swing in PD to reference data



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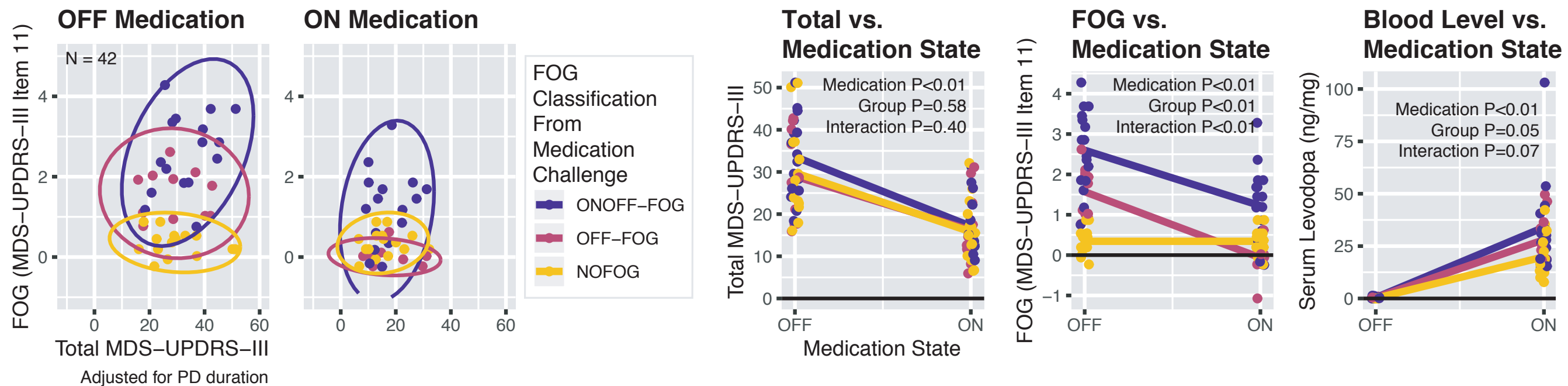
Freezing of gait is poorly understood but a major contributor to falls in Parkinson's disease

- “A brief arrest of stepping when initiating gait, turning, and walking straight ahead”¹
- ~2nd largest predictor of fall risk.²
- “ON” state FoG reported by patients ($\approx 38\%$)³ has been called “pseudo-ON” or “levodopa-induced”⁴

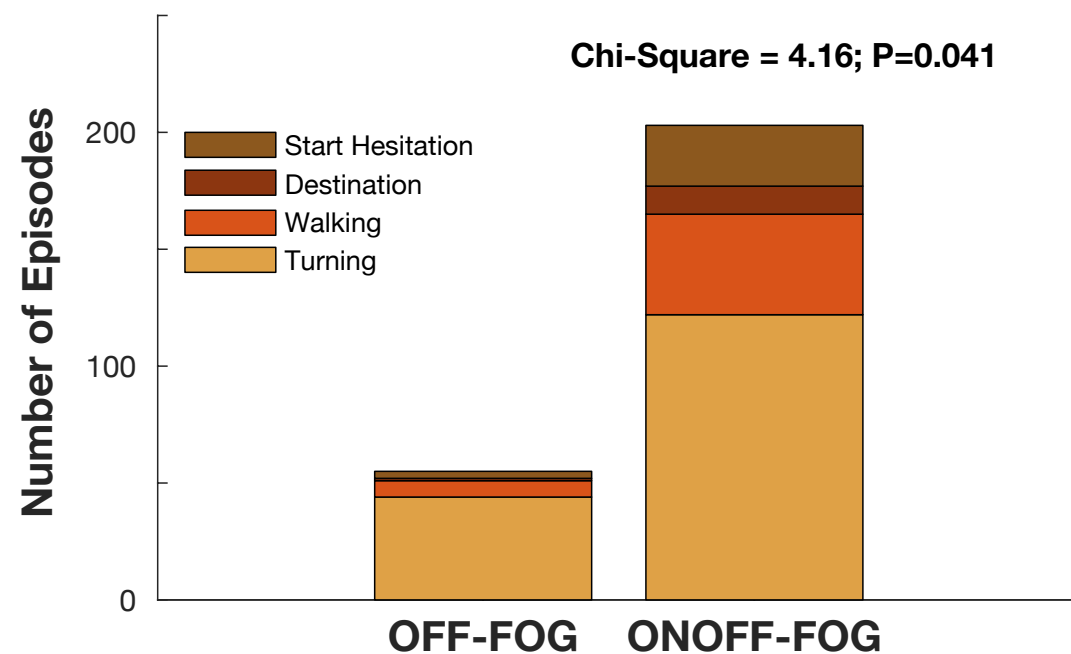
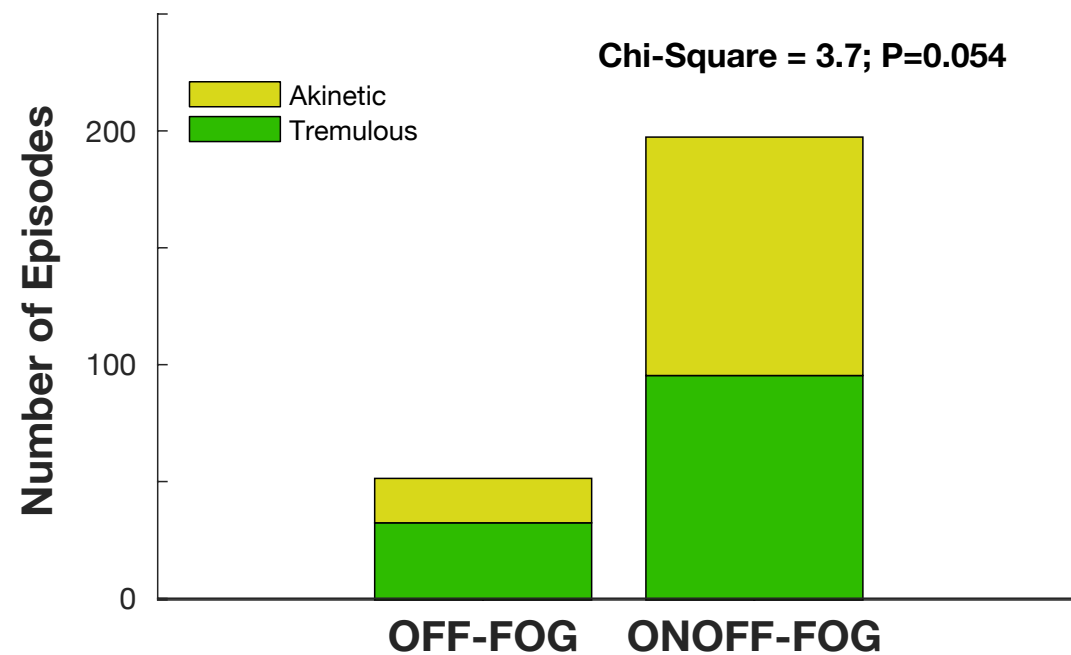


Lancet TV – <https://www.youtube.com/watch?v=3-wrNhyVTNE>

Freezing of gait can persist even in the presence of ample levodopa



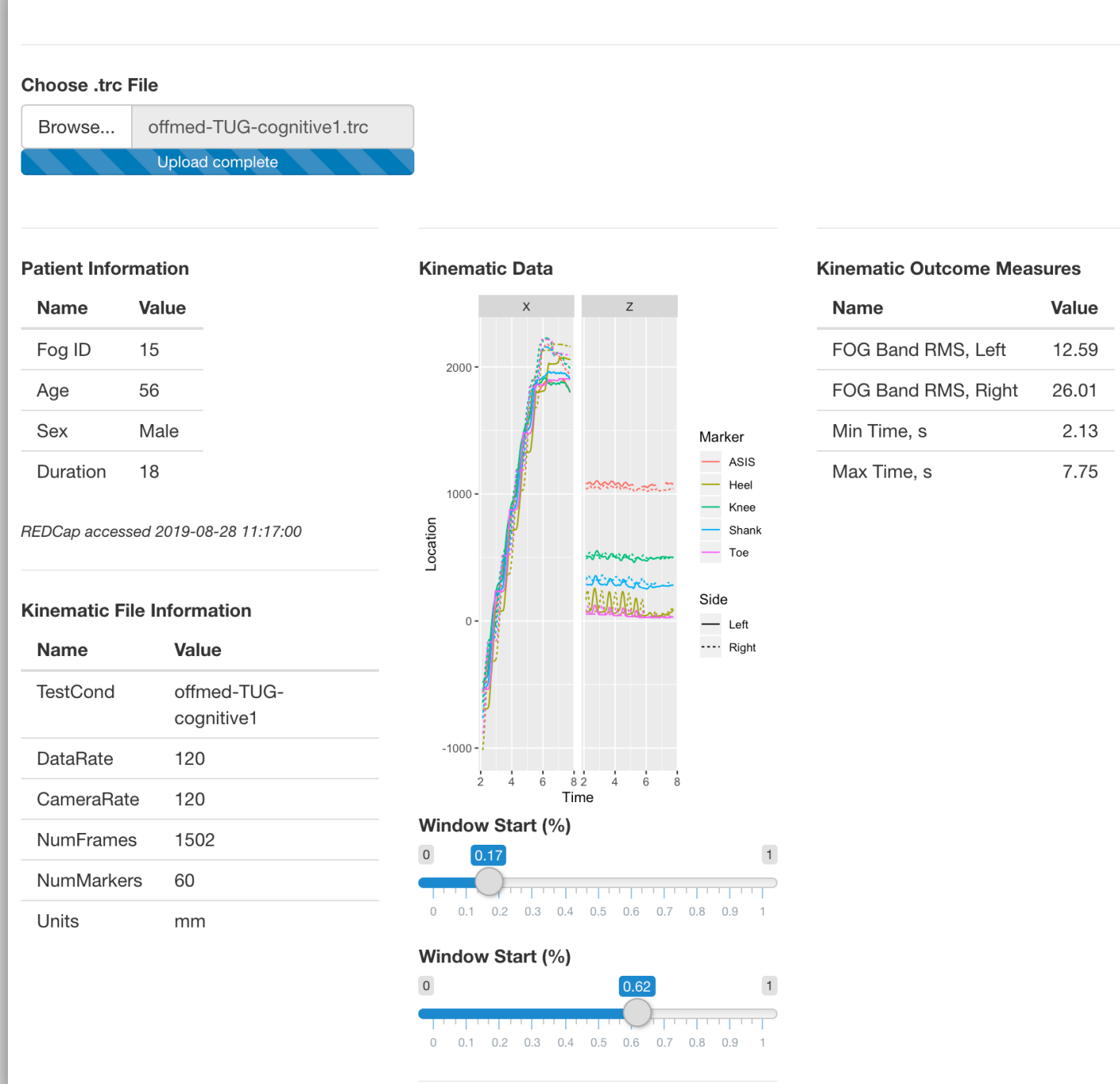
Quantifying FOG based on amplitude thresholding is difficult



- **Akinetic vs. tremulous episodes** are more common in unresponsive freezing.
- Traditional signal processing can probably not differentiate akinetic episodes from standing still.
- LSTM approaches may help.
- **Episodes during straight walking vs. turning** are more common in unresponsive freezing.
- This may provide insight analogous to how action vs. postural tremor may differentiate essential tremor from PD.
- Expert annotations boosted with crowdsourcing may help.

We are developing an extensible analysis platform to quantify and annotate FOG and other PD features in clinic data

FOG Kinematic Data Visualization



- Web-based interface (shinyapps.io)
- Integration with patient-level data via REDCap API
- Persistent HIPAA-compliant storage in AWS

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Closing remarks

1. Projects using motion capture in movement disorders will be more impactful if they are **clinical need-led**, rather than technology-led.
2. Projects should use **open source tools** for conceptual reasons (projects must scale) and practical reasons (clinic computers do not run analysis software).
3. Projects should be **tolerant to variation in data structure** (currently ≈ 2500 kinematic variables for each observation of each patient), especially as data collection changes over time and across sites.

tiny.cc/jlucasmckay



Thank you!



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EMORY
UNIVERSITY
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MEDICINE

Department of Neurology



Eunice Kennedy Shriver National Institute
of Child Health and Human Development
Health research throughout the lifespan

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