

Using Technology to Assess Upper Extremity Function (Reachable Workspace) in Neuromuscular Disorders

Jay J. Han, MD

Professor

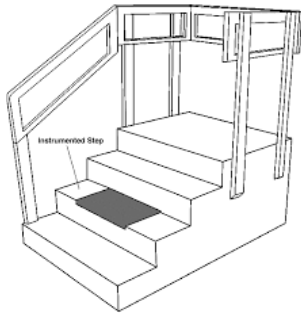
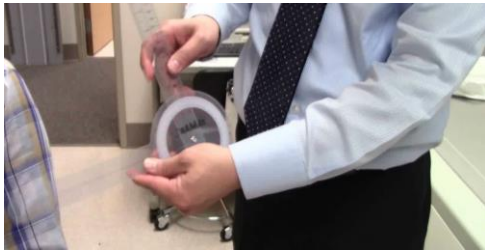
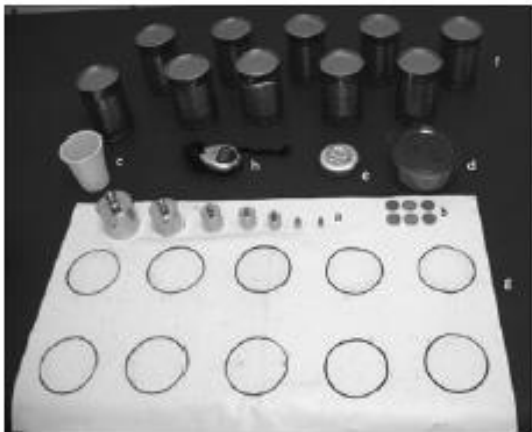
Dept. of Physical Medicine & Rehabilitation

UC Irvine

Advances in Neuromuscular field

- Recent advances in therapeutic developments
 - Neuromuscular field has been active
 - Drug therapies & pharmacologic interventions
 - Gene and cell therapies
 - But also assistive devices and robotics
- Highlight the need for effective outcome measures
 - Improve monitoring of disease severity and progression
 - Better characterization for natural history studies
 - Identify clinical outcome measures for planned efficacy trials

Traditional tools



Upper Extremity Function- Fine Motor, ADL

Please respond to each question or statement by marking one box per row.

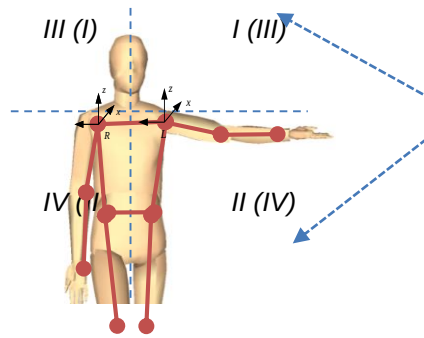
		Without any difficulty	With a little difficulty	With some difficulty	With much difficulty	Unable to do
PFAD0	Are you able to turn a key in a lock?.....	☐	☐	☐	☐	☐
PFAD0	Are you able to brush your teeth?.....	☐	☐	☐	☐	☐
NGUE04 4	Are you able to make a phone call using a touch tone key-pad?.....	☐	☐	☐	☐	☐
PFBD1	Are you able to pick up coins from a table top?.....	☐	☐	☐	☐	☐
PFAD2	Are you able to write with a pen or pencil?.....	☐	☐	☐	☐	☐
PFAD0	Are you able to open and close a zipper?.....	☐	☐	☐	☐	☐
PFAD0	Are you able to wash and dry your body?.....	☐	☐	☐	☐	☐
PFBD0	Are you able to shampoo your hair?.....	☐	☐	☐	☐	☐
PFAD2	Are you able to open previously opened jars?.....	☐	☐	☐	☐	☐
PFBD2	Are you able to hold a plate full of food?.....	☐	☐	☐	☐	☐
PFAD1	Are you able to pull on trousers?.....	☐	☐	☐	☐	☐
PFAD4	Are you able to button your shirt?.....	☐	☐	☐	☐	☐
PFBD1	Are you able to trim your fingernails?.....	☐	☐	☐	☐	☐
PFAD0	Are you able to cut your toe nails?.....	☐	☐	☐	☐	☐
PFAD0	Are you able to bend down and pick up clothing from the floor?.....	☐	☐	☐	☐	☐



Brooke Upper Extremity Rating Scale

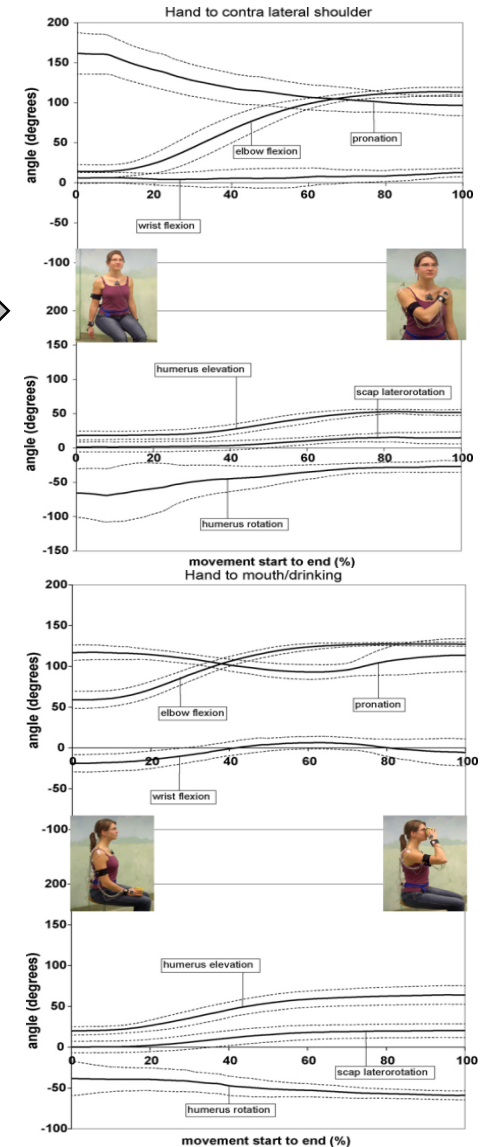
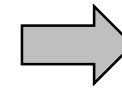
Grade	Description
1	Starting with arms at the sides, the patient can abduct the arms in a full circle until they touch above the head. *
2	Can raise arms above head only by flexing the elbow (shortening the circumference of the movement) or using accessory muscles. *
3	Cannot raise hands above head, but can raise an 8-oz glass of water to the mouth.
4	Can raise hands to the mouth, but cannot raise an 8-oz glass of water to the mouth.
5	Cannot raise hands to the mouth, but can use hands to hold a pen or pick up pennies from the table.
6	Cannot raise hands to the mouth and has no useful function of hands.

Traditional Motion Capture Lab

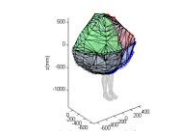
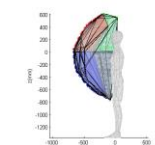
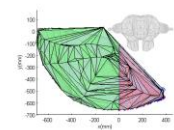
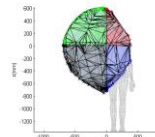
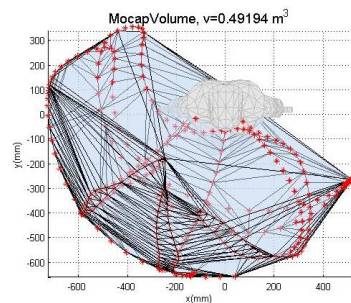
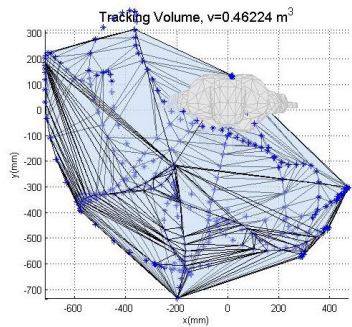
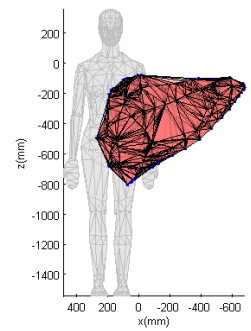
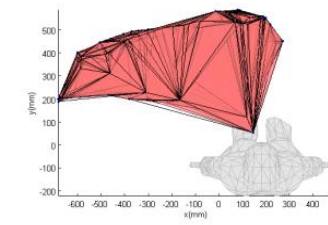
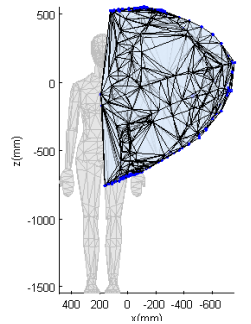
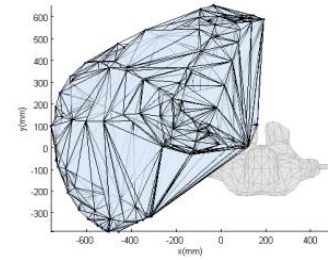
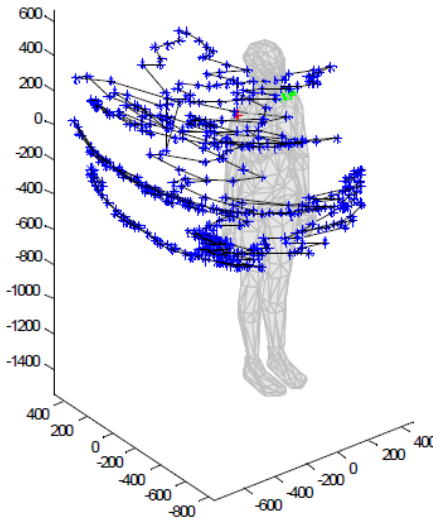
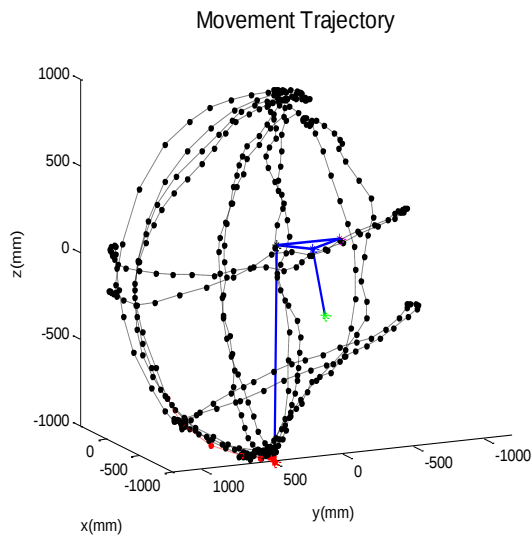


- Large cost
- Space & equipment requirements
- Not very portable
- Marker-based (active or passive)

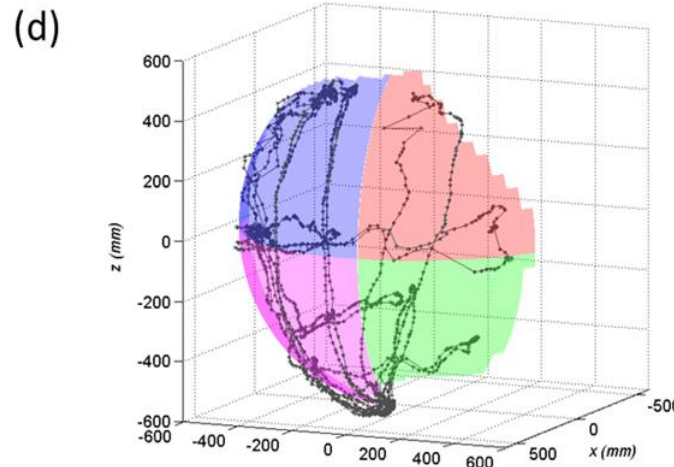
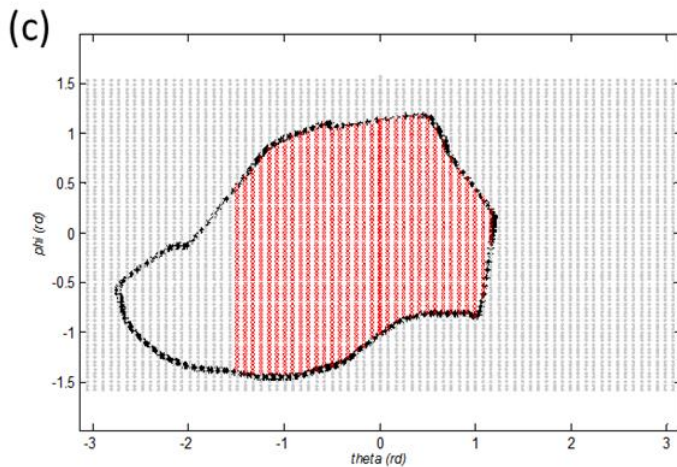
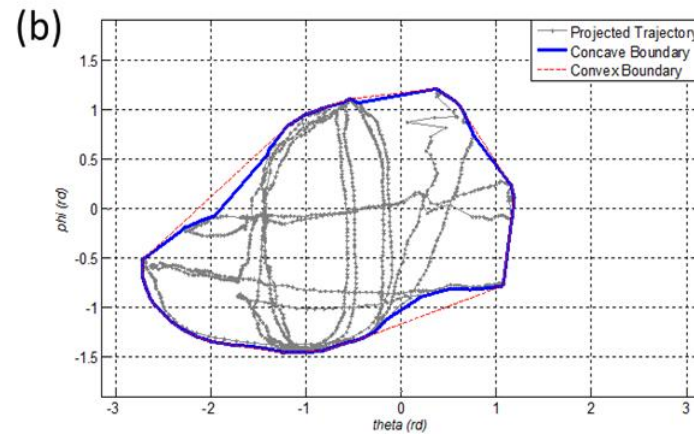
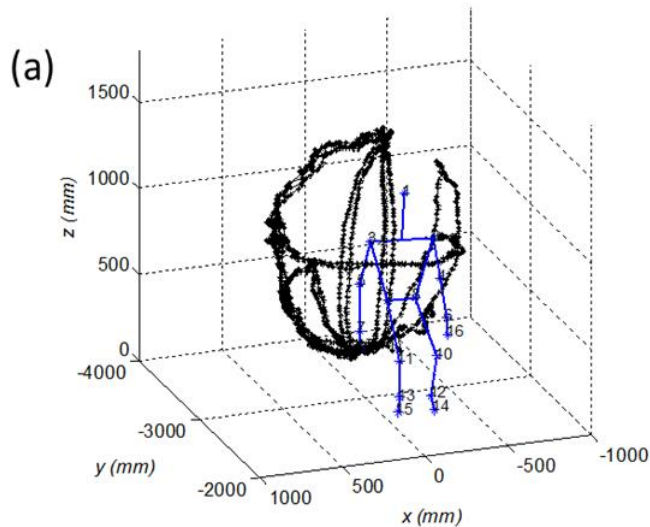
Example output



- Development of algorithm and methods to reconstruct an individual's reachability (Reachable workspace).
- Graphical visualization of reachable workspace (3D)

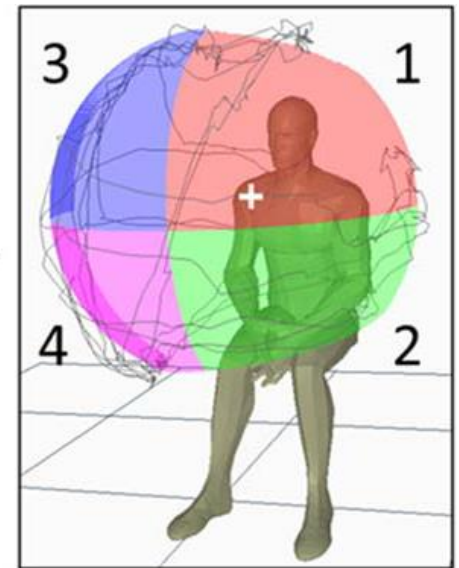
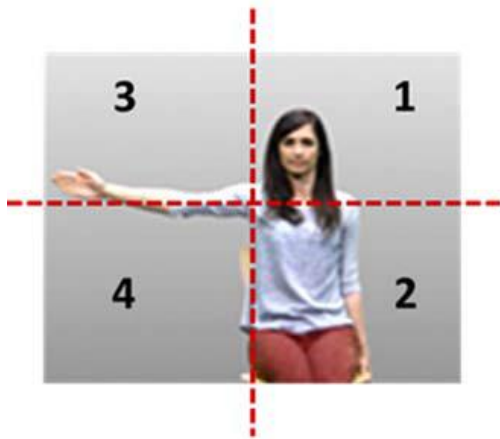


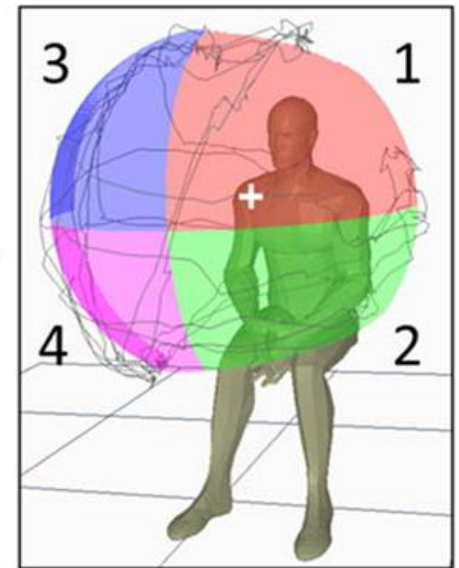
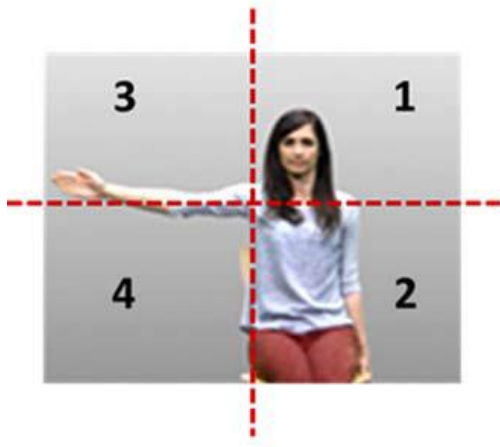
Steps to determining the Reachable Workspace

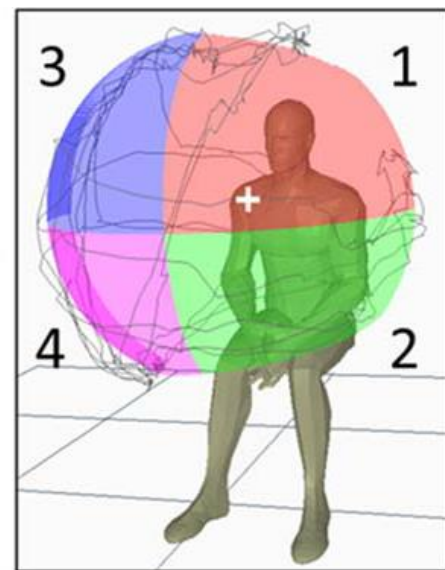
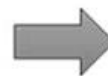
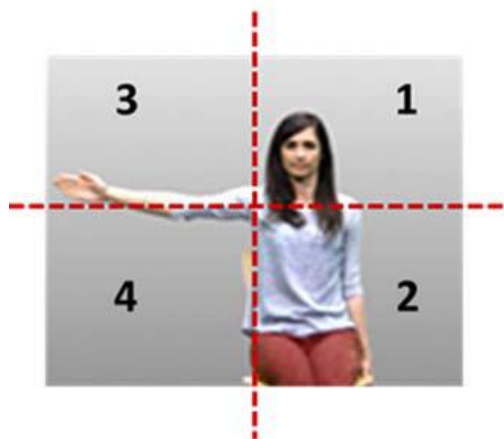


1. Area obtained
2. Normalized by the area of the hemisphere ($2\pi r^2$)
3. Allows comparison between individuals

Relative Surface Area (RSA)







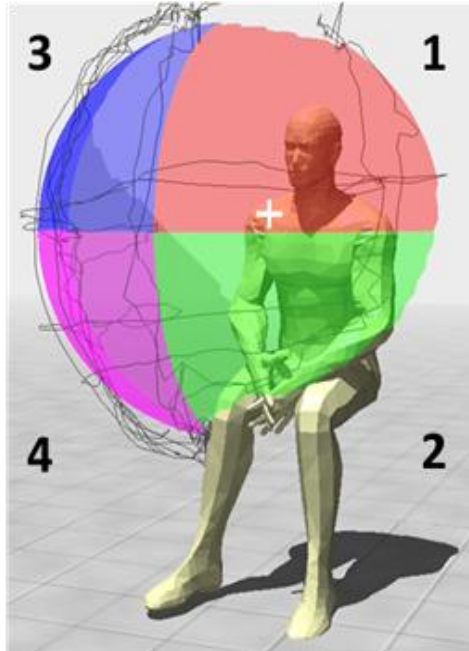
Upper Extremity 3D Reachable Workspace Analysis in Dystrophinopathy Using Kinect

Jay J. Han¹, Gregorij Kurillo^{1,2}, Richard T. Abresch¹,
Evan de Bie¹, Alina Nicorici¹, Ruzena Bajcsy²

¹University of California at Davis School of Medicine

²University of California at Berkeley College of Engineering

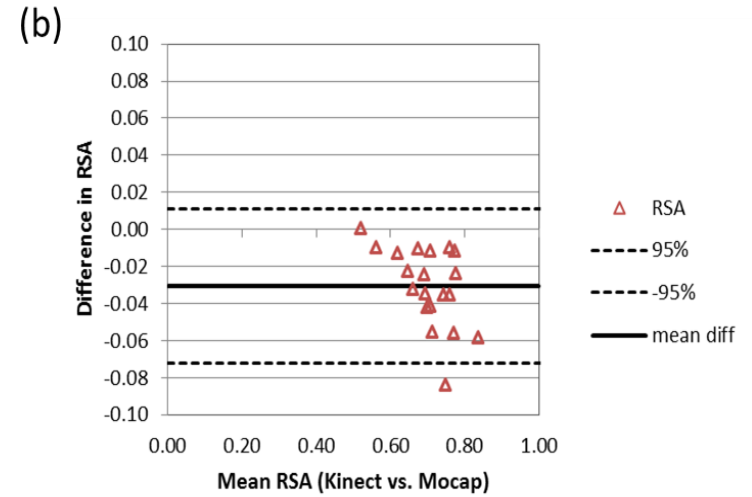
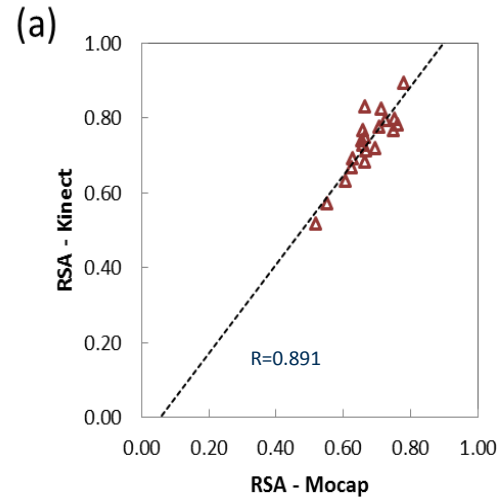
Set up (sensor + display + computer)



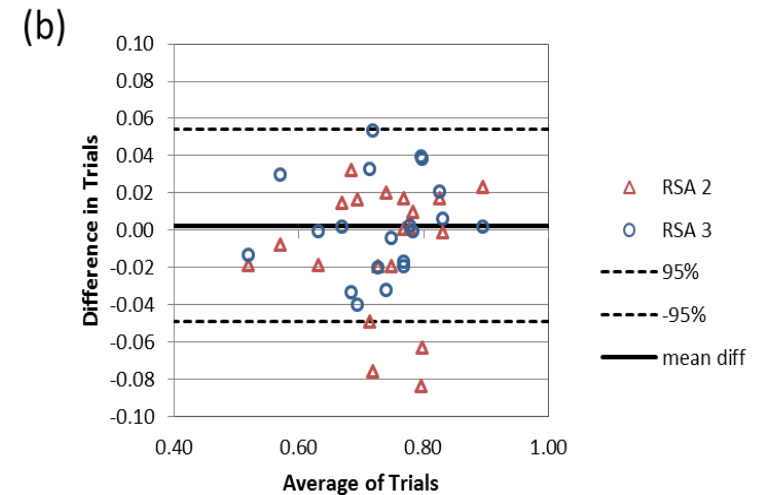
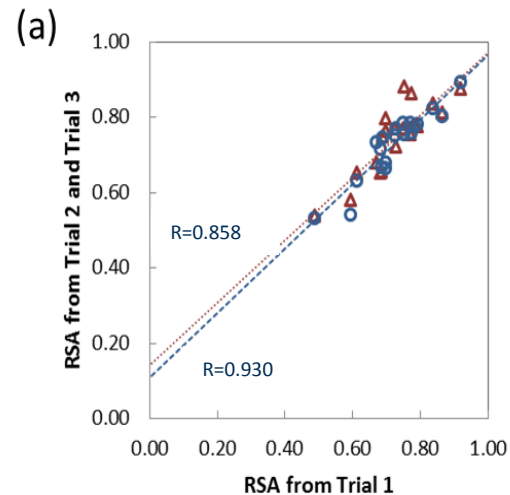
- Simple
- Quick
- Low-cost
- Unobtrusive (no markers)
- Intuitive (visualization of reachable workspace)

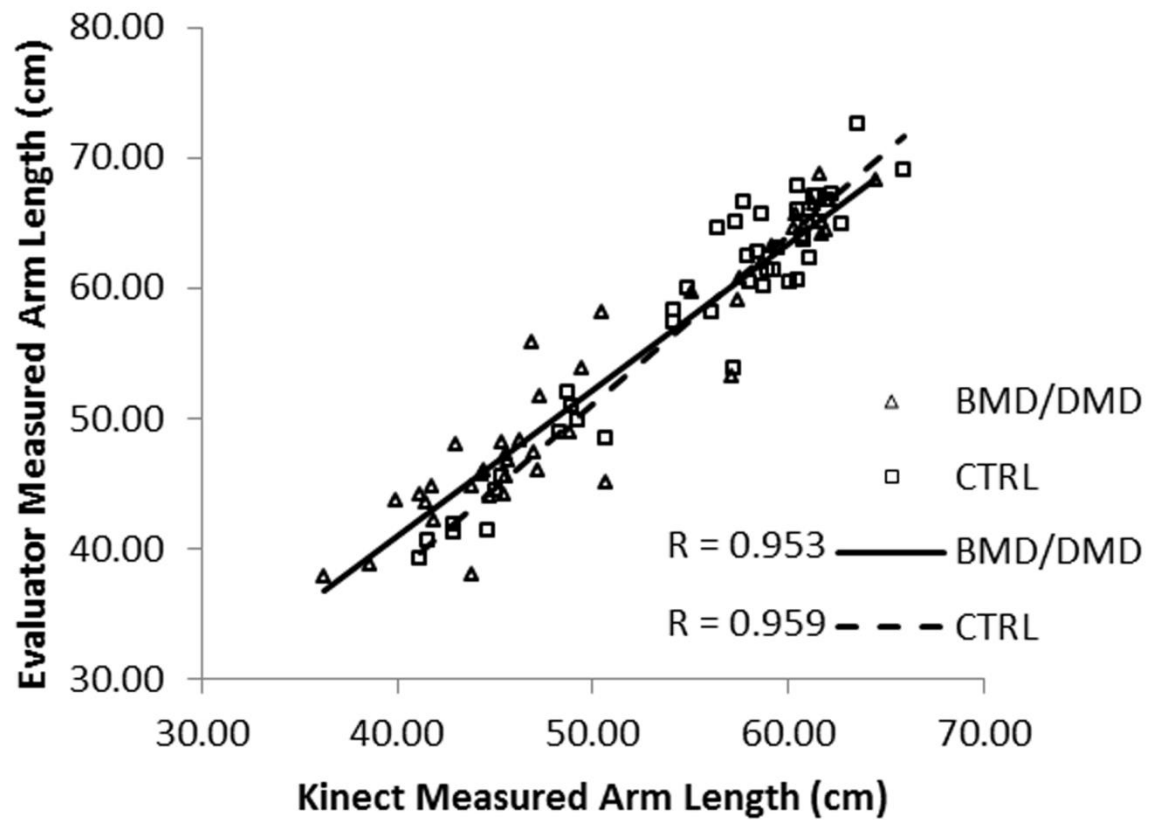
Kinect Reachable Workspace RSA - Reliability testing

Kinect vs. Motion capture



Test and retest

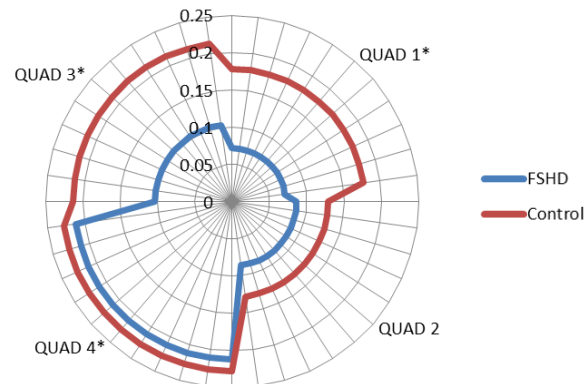
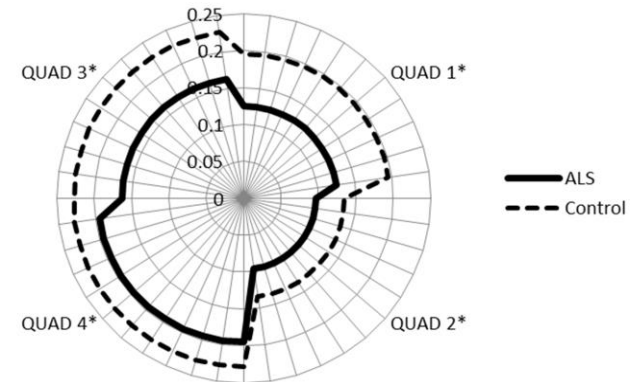
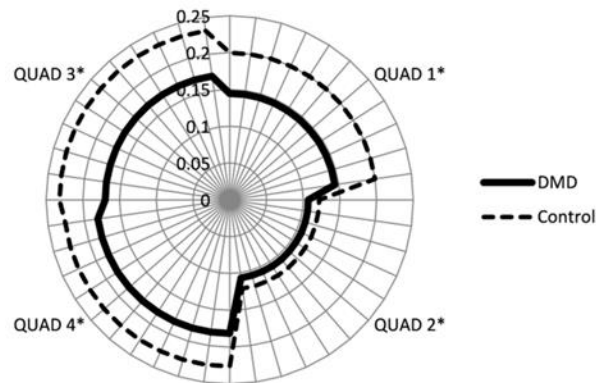
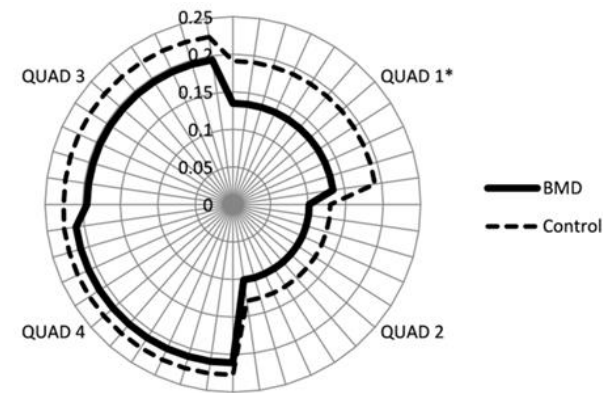




Also, Test re-test reliability in DMD

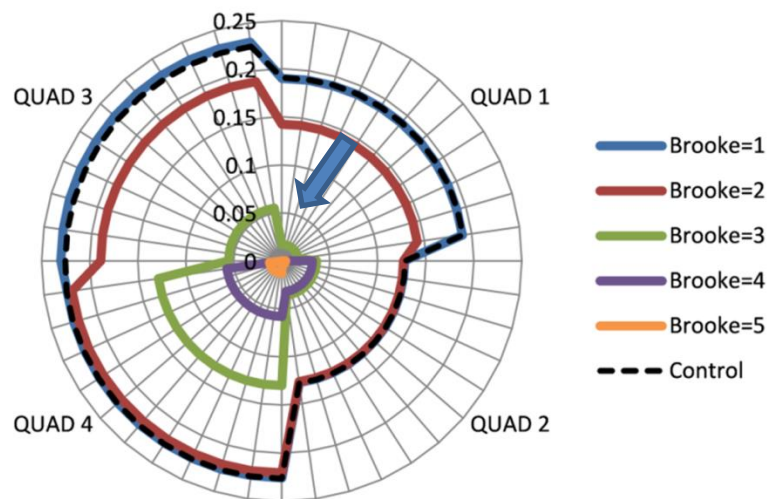
ICC=0.935

Reachable Workspace Differences between: DMD, BMD, FSHD, and ALS

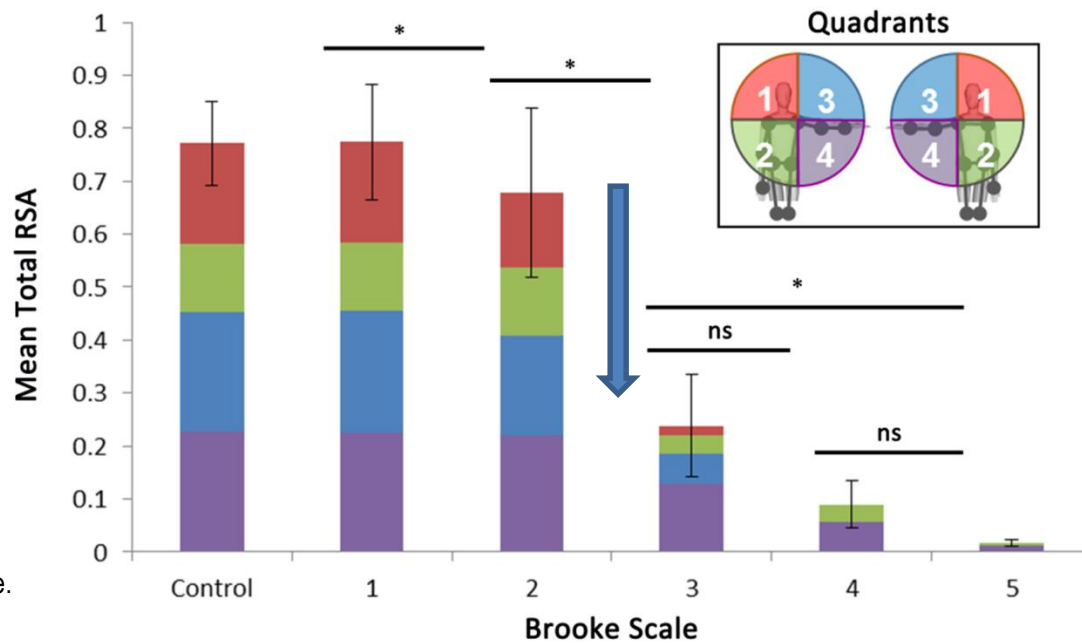


RSA
vs.
Brooke
(DMD)

(A)

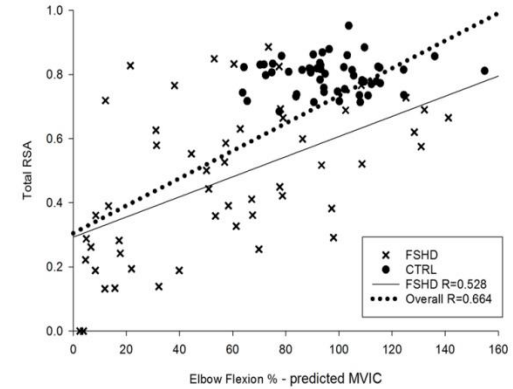
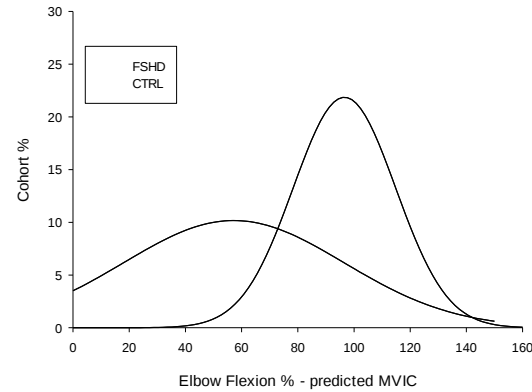


(B)

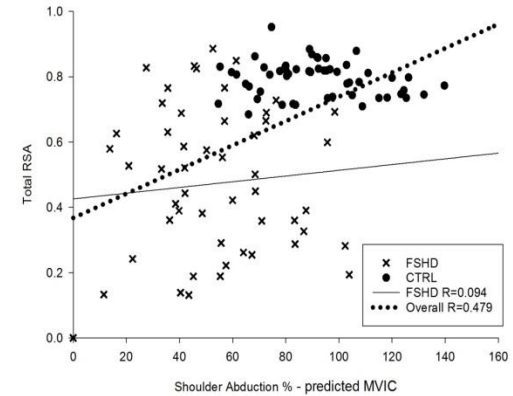
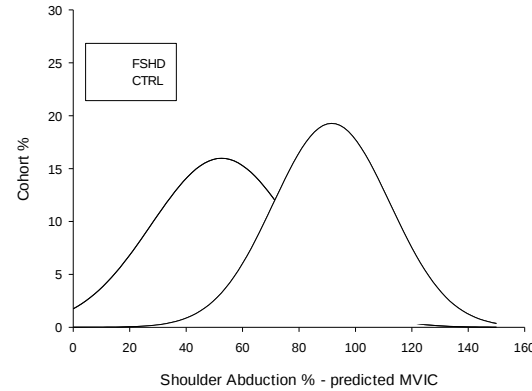


RSA vs. Strength (FSHD)

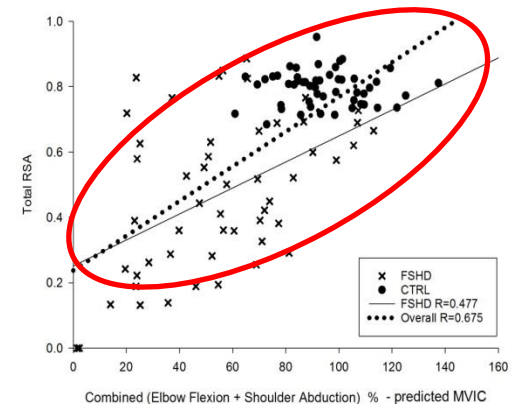
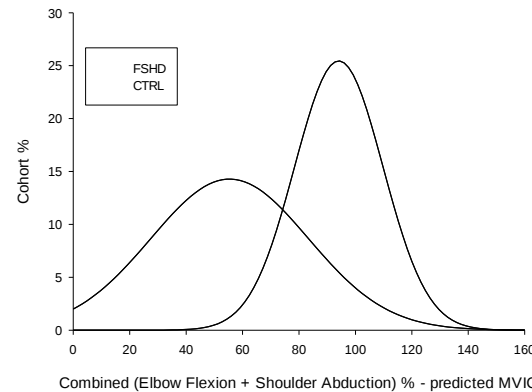
Elbow Flexion



Shoulder Abduction



Combined



No Weight (no loading)

3D View

Top/Bottom View

Left/Right View

Front/Back View

Show Angles

Surface area:

- Quadrant #1: 0.05705 m² (0.034)
- Quadrant #2: 0.2958 m² (0.176)
- Quadrant #3: 0.2141 m² (0.128)
- Quadrant #4: 0.3453 m² (0.206)

Total surface area: 0.9123 m²
Relative surface area: 0.5434

Goniometry:

Forward Flexion: 88.64 Deg
Backward Extension: 0 Deg
Abduction: 109.5 Deg
Adduction: 0 Deg

3D View

Top/Bottom View

Left/Right View

Front/Back View

Show Angles

Surface area:

- Quadrant #1: 0.04698 m² (0.028)
- Quadrant #2: 0.2238 m² (0.135)
- Quadrant #3: 0.2308 m² (0.14)
- Quadrant #4: 0.3614 m² (0.219)

Total surface area: 0.863 m²
Relative surface area: 0.5219

Goniometry:

Forward Flexion: 87.81 Deg
Backward Extension: 63 Deg
Abduction: 99.84 Deg
Adduction: 38.1 Deg

500 Gram wrist weight (~1 lb loading)

3D View

Top/Bottom View

Left/Right View

Front/Back View

Show Angles

Surface area:

- Quadrant #1: 0.03865 m² (0.023)
- Quadrant #2: 0.2619 m² (0.156)
- Quadrant #3: 0.1918 m² (0.114)
- Quadrant #4: 0.3466 m² (0.206)

Total surface area: 0.8389 m²
Relative surface area: 0.4991

Goniometry:

Forward Flexion: 86.91 Deg
Backward Extension: 65.11 Deg
Abduction: 106.8 Deg
Adduction: 43.31 Deg

3D View

Top/Bottom View

Left/Right View

Front/Back View

Show Angles

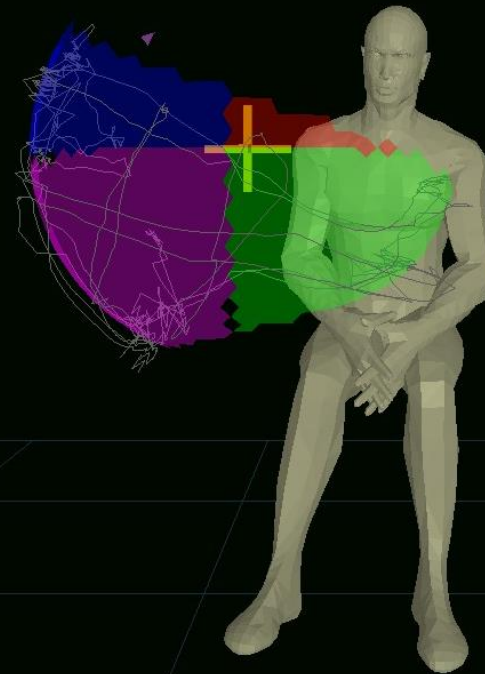
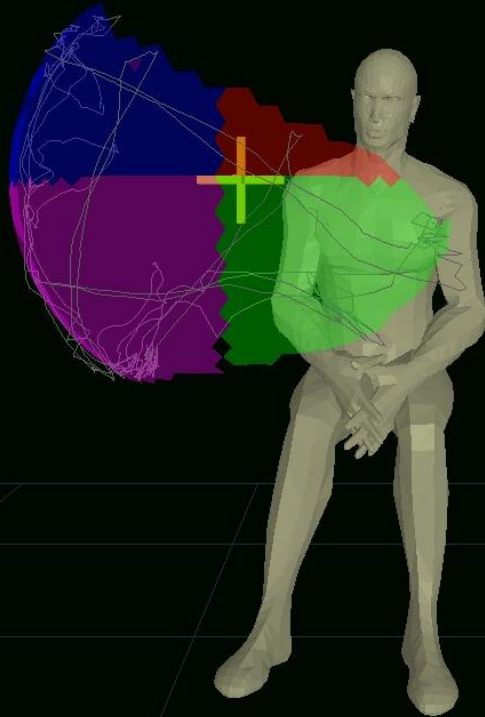
Surface area:

- Quadrant #1: 0.02155 m² (0.0143)
- Quadrant #2: 0.1722 m² (0.114)
- Quadrant #3: 0.1917 m² (0.127)
- Quadrant #4: 0.3165 m² (0.21)

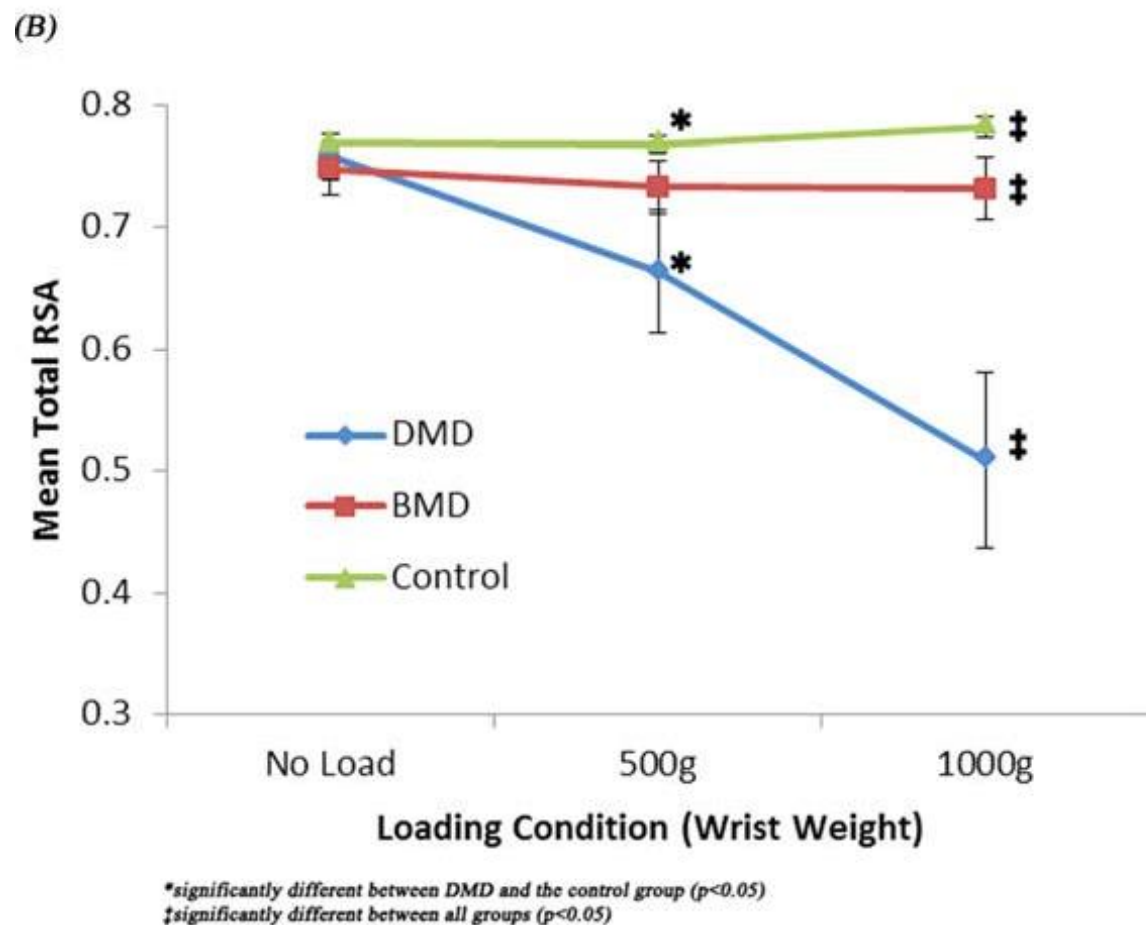
Total surface area: 0.7019 m²
Relative surface area: 0.4665

Goniometry:

Forward Flexion: 74.02 Deg
Backward Extension: 0 Deg
Abduction: 98.87 Deg
Adduction: 40.61 Deg



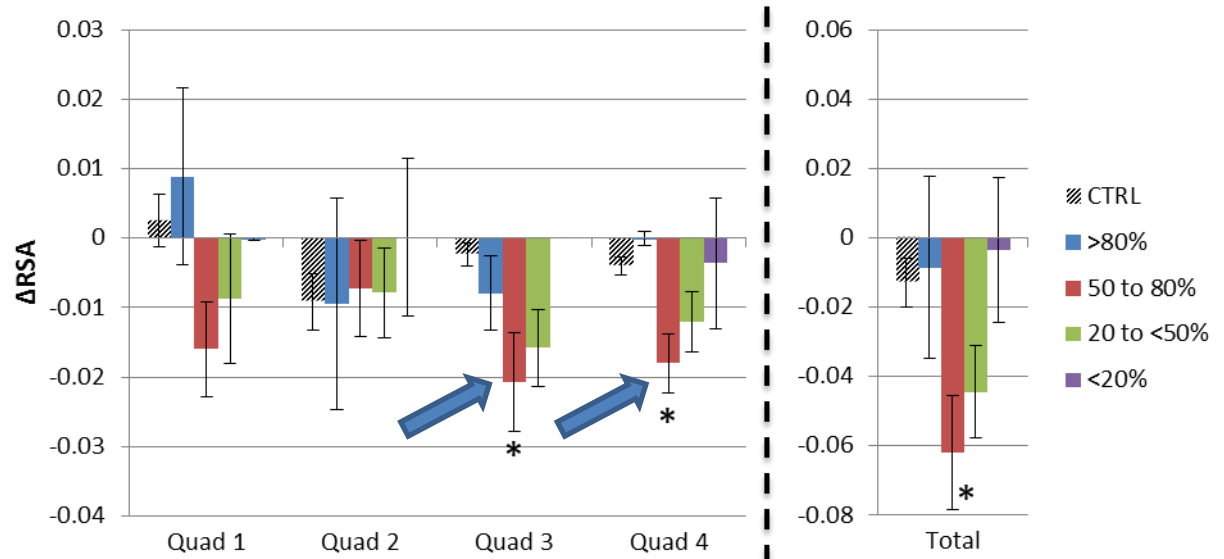
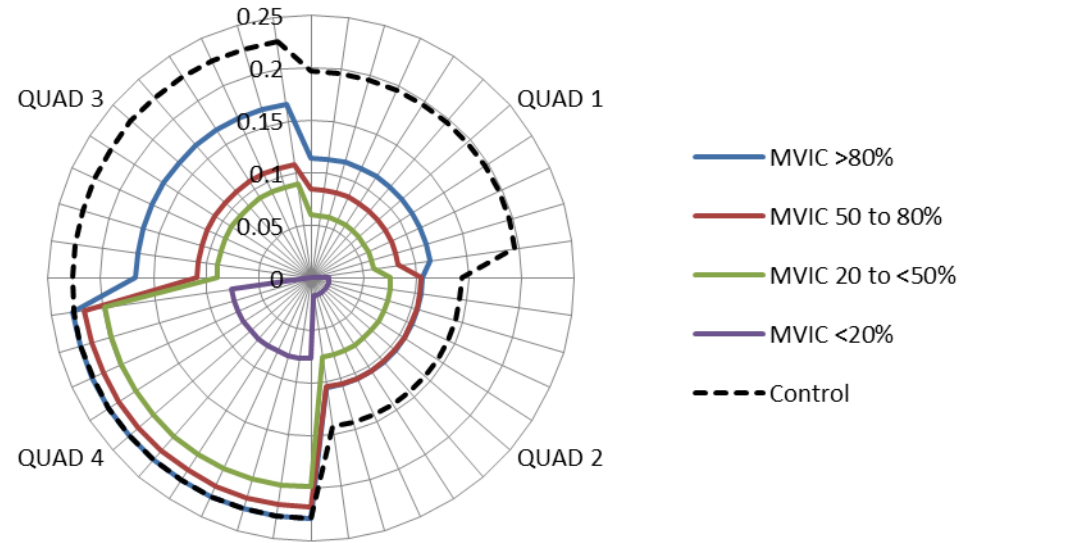
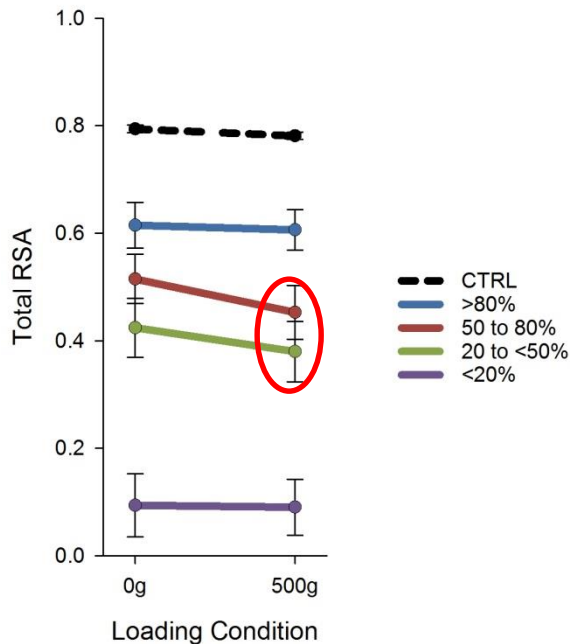
Using simple wrist-weight to detect subtle differences in Reachability



FSHD:

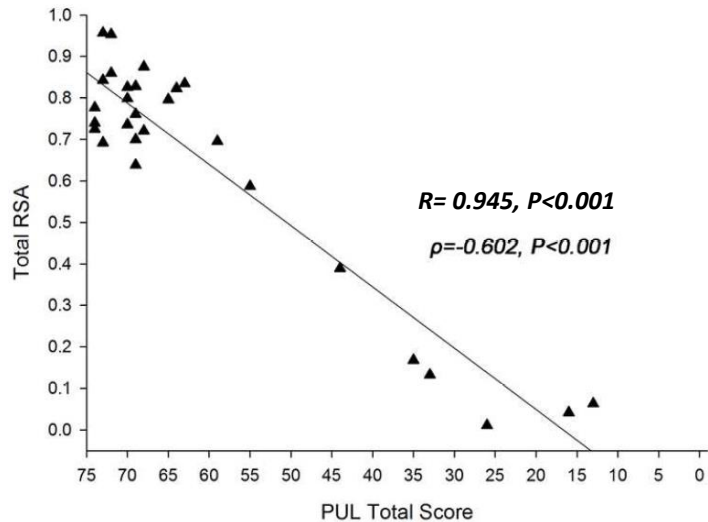
Reachable workspace by QMT

- Shoulder Abduction
- Elbow Flexion



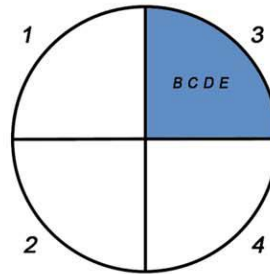
* one-way ANOVA with Tukey' post hoc analysis, cohort significantly different than controls ($p < 0.05$)

RSA correlates well with PUL



Mapping PUL dimensional scores and individual items to reachable workspace quadrants

Shoulder Dimension Items



Rank Order of Difficulty of PUL Items according to RASCH analysis with Items listed in order of difficulty (from most difficult to least difficult as determined by Mayhew et al.)

C: Shoulder abduction above shoulder height

Elbow to eye level

E: Shoulder Flexion above shoulder height

Elbow to eye level

B: Shoulder abduction to shoulder height

Elbow to shoulder level

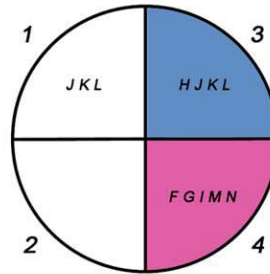
D: Shoulder flexion to shoulder height

Elbow to shoulder level

PUL Scoring for shoulder dimension items:

0 = ; 1 = Able no weights; 2 = 200g; 3 = 500g; 4 = 1000g

Middle Dimension Items



H: Move weight on table

Sliding or lifting either 100g, 200g, 500 g, or 1000g from outer to center circle without compensation)

F: Hands to mouth

Ability to bring 50g or 200 g in cup to mouth using either 1 or 2 hands and either with or without elbow support)

L: Stacking heavy cans

5 heavy cans

J: Lifting heavy cans

5 heavy cans

G: Hand(s) to table from lap

Ability to get one or both hands from lap to table either incompletely or completely and either one at a time or simultaneously

N: Tearing paper

ability to hold and tear sheet of paper either unfolded or folded in 2 or 4, beginning from the fold edge

I: Lifting Light cans

5 light cans

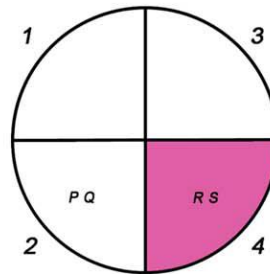
K: Stacking Light Cans

5 light cans

M: Remove lid from container

Ability to remove a lid and open container completely*

Distal Dimension Items



Q: Turning Light

ability to pick up the light, and turns the hand over completely or incompletely and with or without compensatory movements)

P: Pushing on the light

Able to turn the light on momentarily or permanently with one hand

O: Tracing path

Ability to pick up pencil and ability to complete tracing of the path with or without stops and with or without raising hand from paper

R: Picking up Coins

Ability to pick up and hold one, three, or six coins in one hand

S: Placing finger on number diagram

Ability to raise finger and place it successively on the numbers of the diagram without touching the lines

T: Lifting with finger pinch grip, U: Lifting with 3 point grip and V: Lifting with Thumb (key) grip were added after the RASCH analysis to reduce floor effects

RASCH analysis showed item M to be easier than item Q.

More Difficult Items



Easier Items

(Less severely affected persons able to perform)

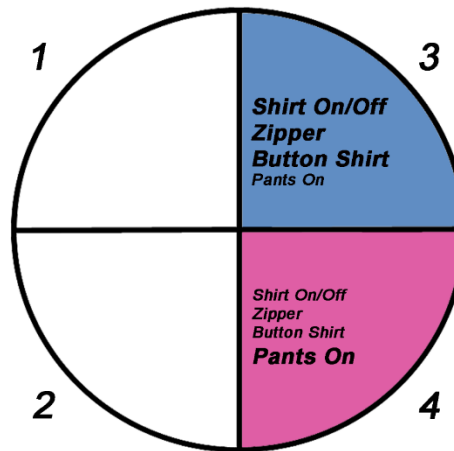
(More severely affected persons able to perform)

Mapping ADL functions (PRO – NeuroQOL) to Reachable workspace Quadrants

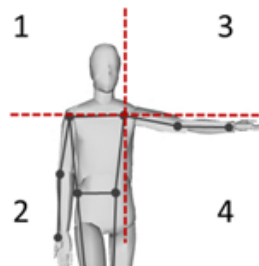
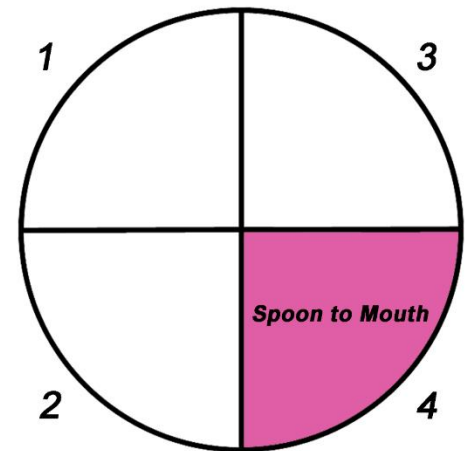
Hygiene



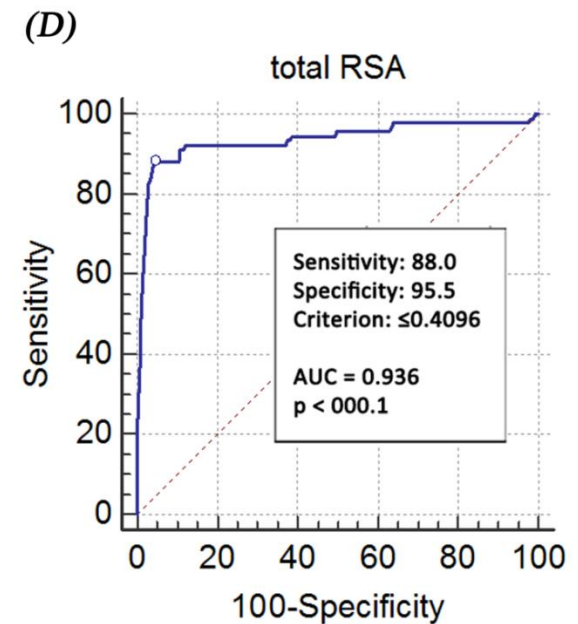
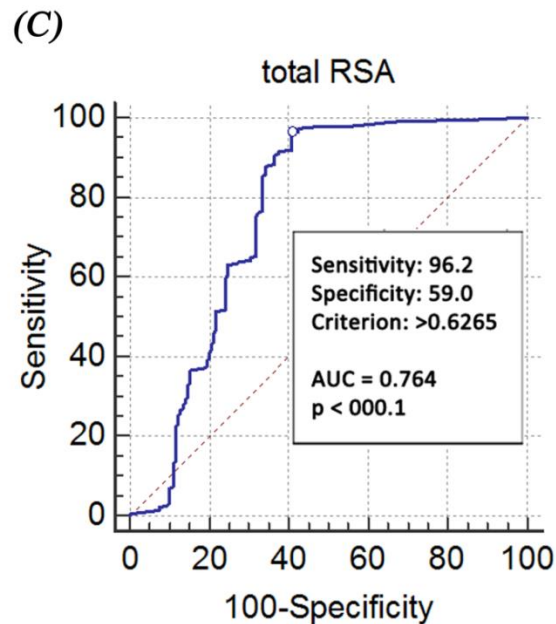
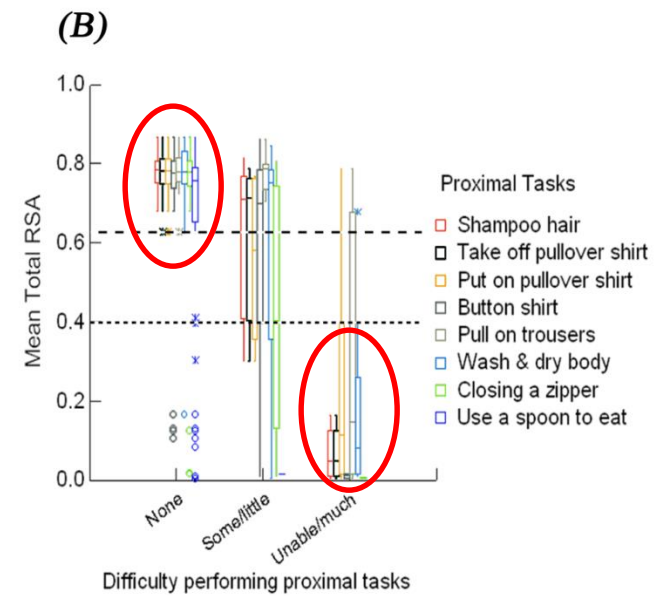
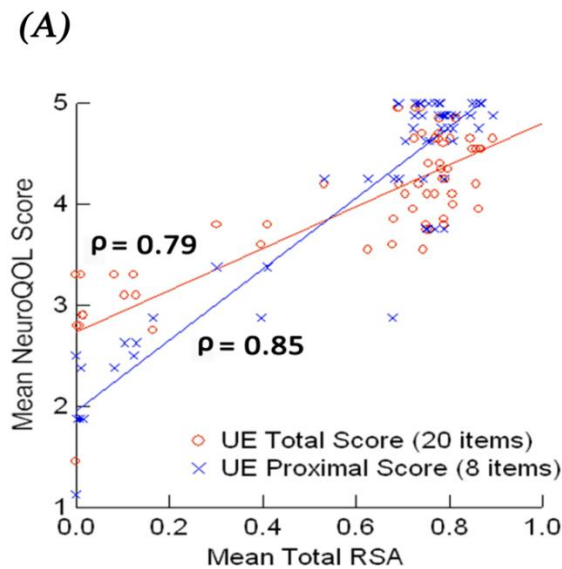
Dressing



Feeding



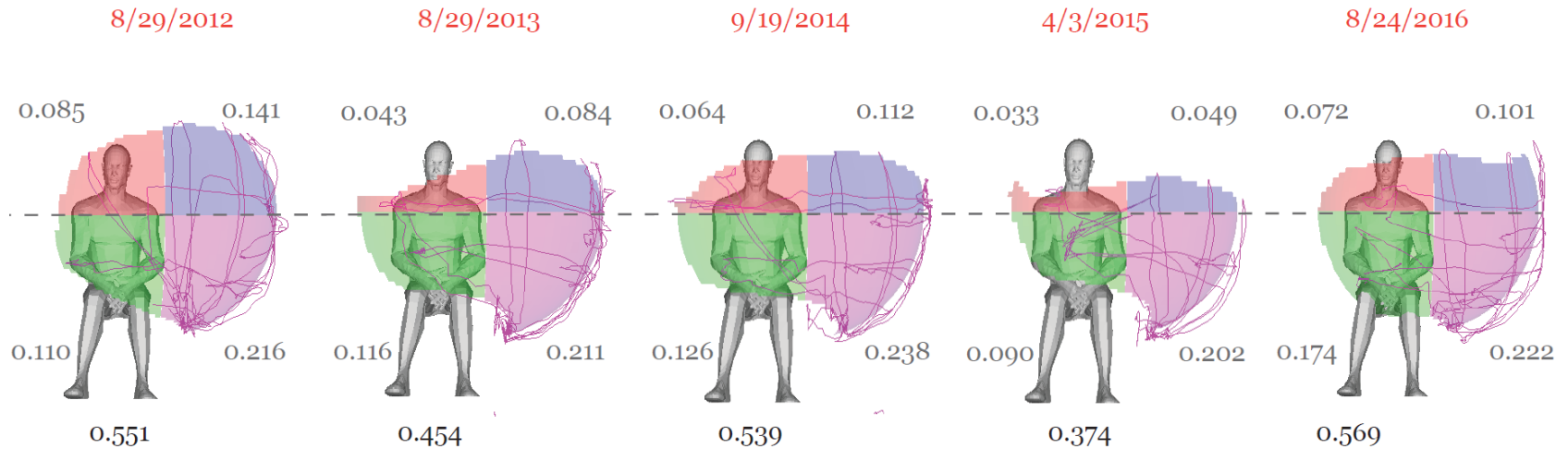
Reachable workspace correlation with ADLs



FSHD: Longitudinal study (18 subjects: 8mo-5yrs, ave 2.5yrs)

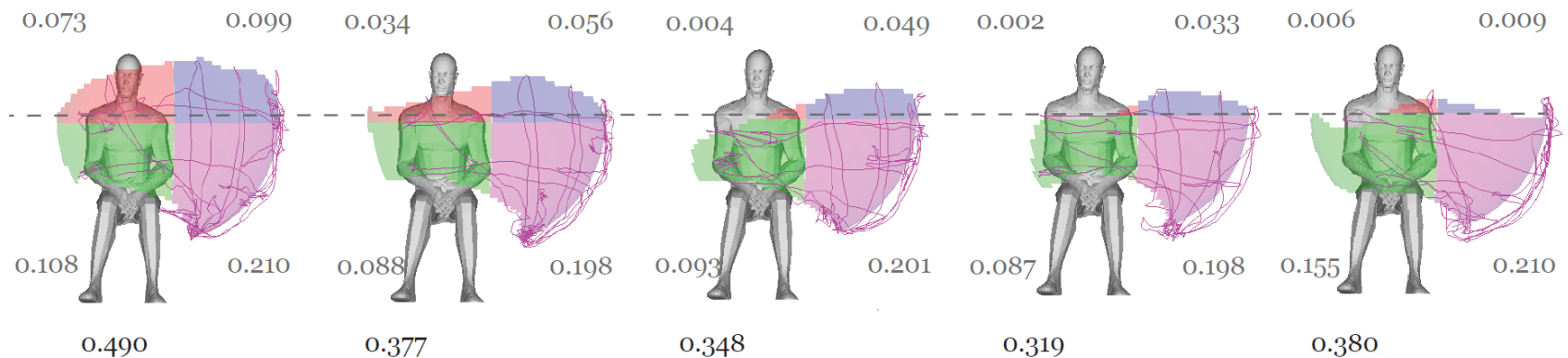
A

subject 201005: left side, No weight

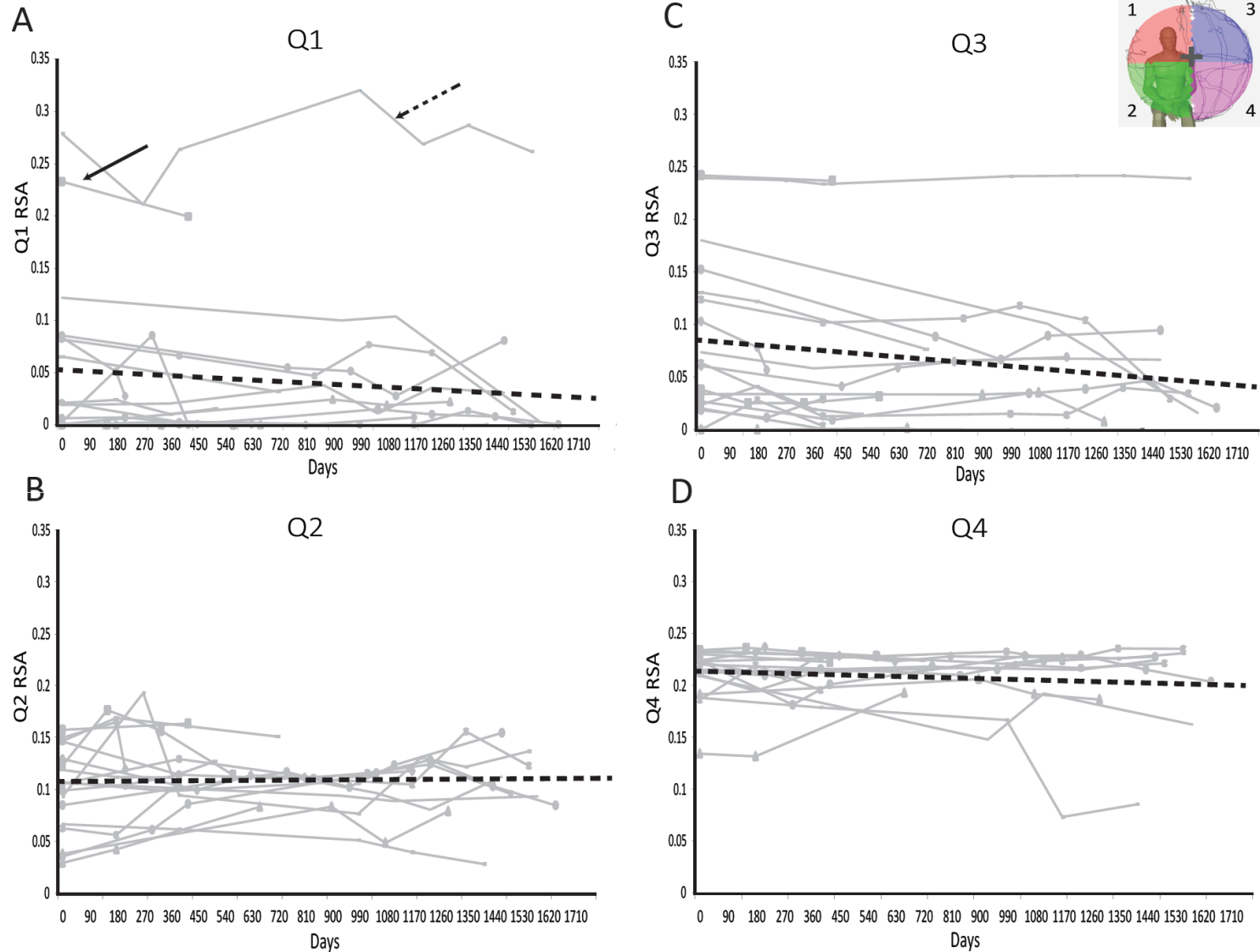


B

subject 201005: left side, 0.5kg weight

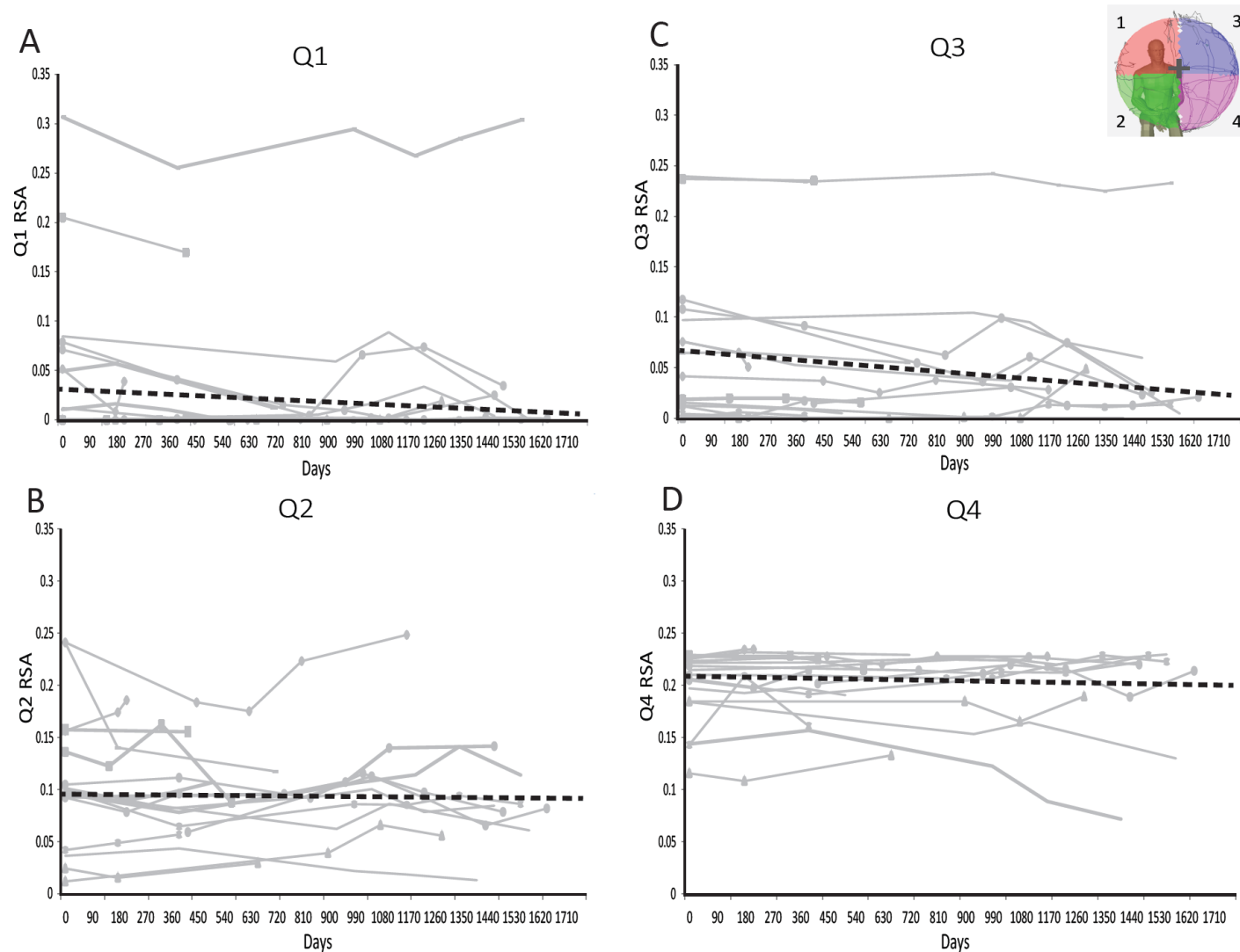


FSHD: Longitudinal (8mo-5 years follow up)

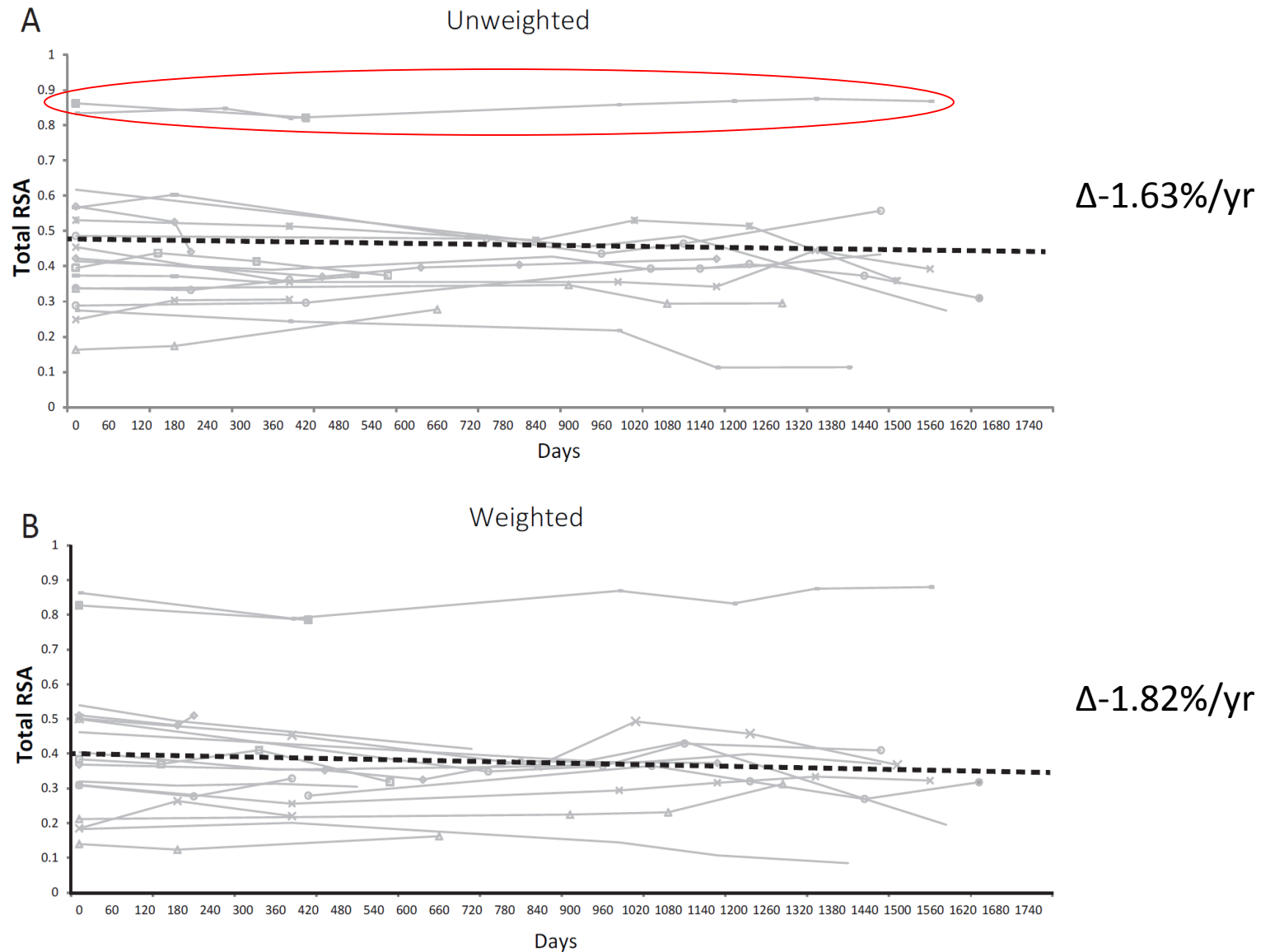


Hatch et al. Longitudinal Study of Upper Extremity Reachable Workspace in FSHD. *Neuromuscular Disorders* (2019). doi: <https://doi.org/10.1016/j.nmd.2019.05.006>

FSHD Longi: 500g weight



FSHD Longitudinal: 18 subjects followed 8mo-5yrs (ave. 2.5 years)



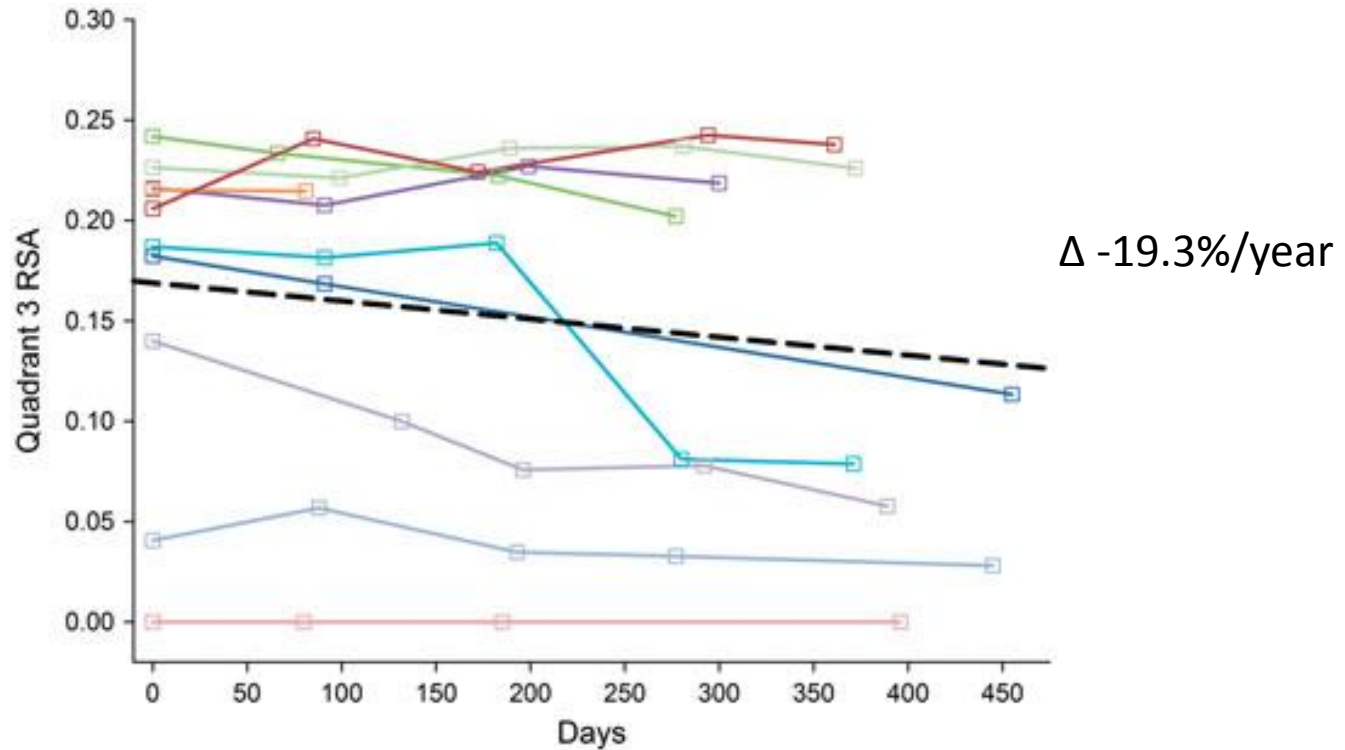
A. Entire cohort

	Intercept + S.E.	Slope + S.E.	Calculated Rates (% per year)	Slope P- value
Quadrant 1	0.05511 $\pm$ 0.01764	-0.00001 $\pm$ 0.0541e ⁻⁰⁴	- 6.62	0.063
Quadrant 1 weighted	0.04417 $\pm$ 0.01765	-0.0871e ⁻⁰⁴ $\pm$ 0.0426e ⁻⁰⁴	-7.20	0.041*
Quadrant 2	0.10415 $\pm$ 0.00815	0.054500e ⁻⁰⁴ $\pm$ 0.0546e ⁻⁰⁴	+ 1.91	0.319
Quadrant 2 weighted	0.09185 $\pm$ 0.00997	0.035200e ⁻⁰⁴ $\pm$ 0.0459e ⁻⁰⁴	+1.40	0.443
Quadrant 3	0.08285 $\pm$ 0.01661	-0.000021 $\pm$ 0.0566e ⁻⁰⁴	- 9.25	0.000*
Quadrant 3 weighted	0.06316 $\pm$ 0.01650	-0.000014 $\pm$ 0.0413e ⁻⁰⁴	-8.09	0.001*
Quadrant 4	0.21091 $\pm$ 0.00665	-0.0426e ⁻⁰⁴ $\pm$ 0.0442e ⁻⁰⁴	- 0.74	0.334
Quadrant 4 weighted	0.20123 $\pm$ 0.00848	-0.0421e ⁻⁰⁴ $\pm$ 0.0359e ⁻⁰⁴	-0.76	0.241
Total	0.44781 $\pm$ 0.04147	-0.00002 $\pm$ 0.00001	- 1.63	0.144
Total weighted	0.40010 $\pm$ 0.04379	-0.00002 $\pm$ 0.000011	-1.82	0.039*

B. w/o High-function

	Intercept + S.E.	Slope + S.E.	Calculated Rates (% per year)	Slope P- value
Quadrant 1	0.03252 $\pm$ 0.00759	-0.000012 $\pm$ 0.0500e ⁻⁰⁴	- 13.47	0.016*
Quadrant 1 weighted	0.01952 $\pm$ 0.00553	-0.0844e ⁻⁰⁴ $\pm$ 0.0424e ⁻⁰⁴	-15.78	0.047*
Quadrant 2	0.09956 $\pm$ 0.00838	0.0678e ⁻⁰⁴ $\pm$ 0.0527e ⁻⁰⁴	+ 2.48	0.198
Quadrant 2 weighted	0.08876 $\pm$ 0.01034	0.0860e ⁻⁰⁴ $\pm$ 0.0490e ⁻⁰⁴	+3.54	0.861
Quadrant 3	0.06344 $\pm$ 0.01030	-0.0000231 $\pm$ 0.0625e ⁻⁰⁴	- 13.20	0.000*
Quadrant 3 weighted	0.04094 $\pm$ 0.00785	-0.0000143 $\pm$ 0.0454e ⁻⁰⁴	-12.75	0.002*
Quadrant 4	0.20982 $\pm$ 0.00731	-0.0582e ⁻⁰⁴ $\pm$ 0.0497e ⁻⁰⁴	- 1.01	0.243
Quadrant 4 weighted	0.19855 $\pm$ 0.00920	-0.0522e ⁻⁰⁴ $\pm$ 0.0402e ⁻⁰⁴	-9.60	0.194
Total	0.40036 $\pm$ 0.02649	-0.000027 $\pm$ 0.000016	- 2.47	0.093
Total weighted	0.34853 $\pm$ 0.02660	-0.000029 $\pm$ 0.000012	-3.04	0.016*

ALS longitudinal data



de Bie E, Oskarsson B, Joyce NC, Nicorici A, Kurillo G, Han JJ. Longitudinal evaluation of upper extremity reachable workspace in ALS by Kinect sensor. Amyotroph Lateral Scler Frontotemporal Degener. 2017 Feb;18(1-2):17-23

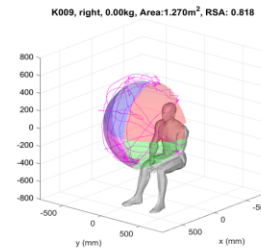
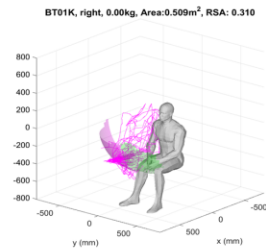
Oskarsson B, Joyce NC, De Bie E, Nicorici A, Bajcsy R, Kurillo G, Han JJ. Upper extremity 3-dimensional reachable workspace assessment in amyotrophic lateral sclerosis by Kinect sensor. Muscle Nerve. 2016 Feb;53(2):234-41.

Pompe patients: pre- & post-ERT

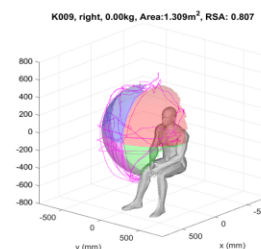
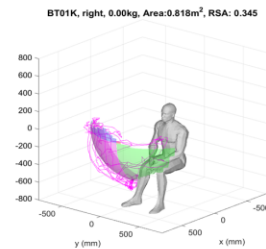
Subject 105

Subject 107

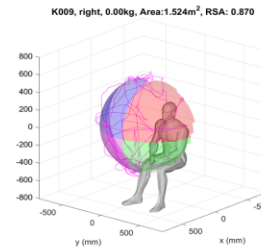
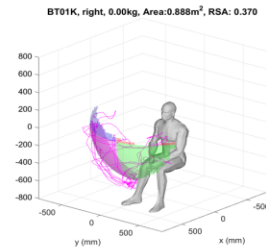
Pre



3 months post



6 months post



Clinical Trial & in-clinic RWS system



- >20 systems deployed around the world (NA, South America, Asia, Europe)
 - Neuromuscular conditions
 - Neurological
 - Orthopedic & musculoskeletal
 - Post breast cancer rehab
 - Drug trial
- Portable system can be taken to patient's home (laptop, tripod+Kinect)
- Cloud-based system
 - Internet sign-on
 - Automatic data upload to cloud server



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Thank you !

