Movement Therapy Robots

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Portions of this material provided by
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U.S. Demographics of Potential Therapy Robot Users

- Stroke:
  - 800,000 cases per year (incidence)

- Cerebral palsy:
  - 300,000 - 500,000 prevalence
  - 8,000 incidence

- Orthopedic interventions:
  - Post knee & hip replacement exercise
  - Ankle surgery
  - Trauma

Stroke Rehabilitation Strategies

- Important variables in optimal rehabilitation
  - Quantity
  - Duration
  - Intensity/repetition
  - Task-specific
- Robotic control strategies
  - Assisting movement
  - Challenging movement
  - Simulating normal tasks
  - Non-contact coaching

D. Jack et al. Virtual Reality-Enhanced Stroke Rehabilitation. *Neural Systems and Rehabilitative Engineering,* 9(3): 308-318, 2001.

L. Marchal-Crespo et al. Review of control strategies for robotic movement training after nuerologic injury. *Journal of NeuroEngineering and Rehabilitation,* 6(20): 2009.

Research Phases in Robot-Assisted Stroke Therapy

1. Replicating the therapist
2. Augmenting the therapist
3. Designing the super-therapist
4. Enabling the inner therapist

H.F. Machiel Van der Loos (UCB)

Phase 1:
Replicating the therapist

MIME: Mirror-Image Movement Enabler (PA VA/Stanford)

Robotic system assisting upper limb neuro–rehabilitation

Facilitates paretic elbow and shoulder movement

Four modes of exercise:

- Passive
- Active-Assisted
- Active-Resisted
- Bimanual

C.G. Burgar, P.S. Lum, P.C. Shor, H.F.M. Van der Loos, Development of robots for rehabilitation therapy: the Palo Alto VA/Stanford experience, *Journal of Rehabilitation R&D*, Vol. 37, No.6, November/December, 2000, 663-673.

P.S. Lum, C.G. Burgar, P.C. Shor, M. Majmundar, H.F.M. Van der Loos, Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper limb motor function after stroke, *Archives of PM&R*, vol. 83, 2002, 952-959.

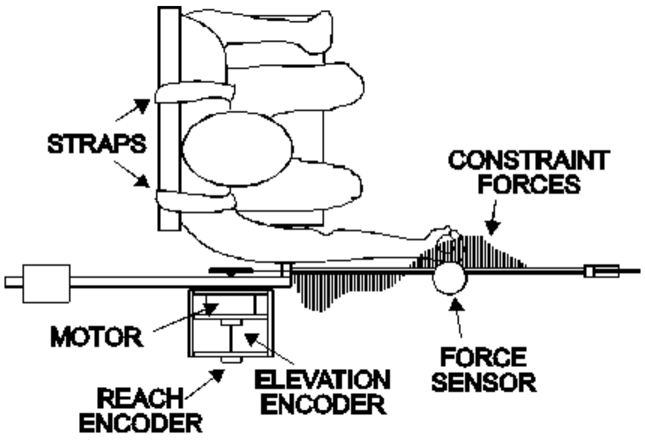
MIT-MANUS, now InMotion (MIT)

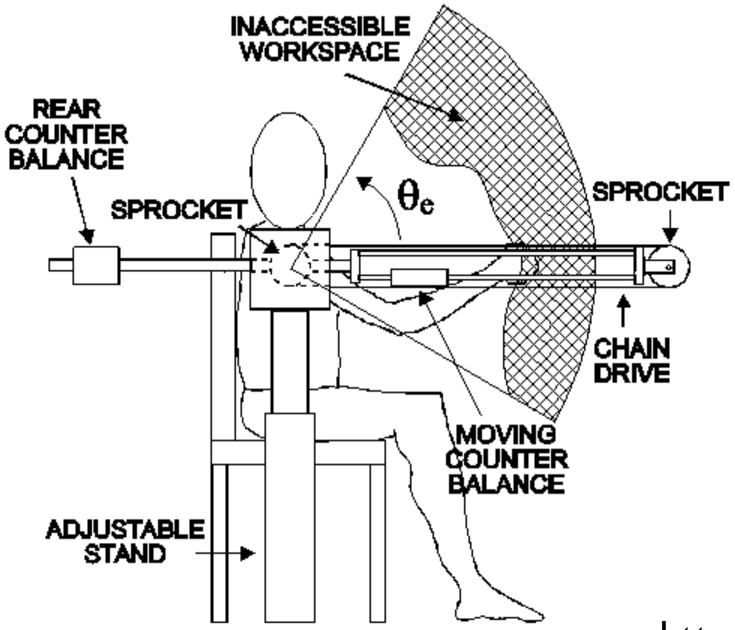
Statistically significant improvement in Fugl-Meyer and clinical strength scales after 4-week regimen of daily 1-hour sessions.

Krebs et al. Increasing Productivity and Quality of Care: Robot-Aided Neurorehabilitation, *VA Journal of Rehabilitation Research and Development* 37:6:639-652, 2000.

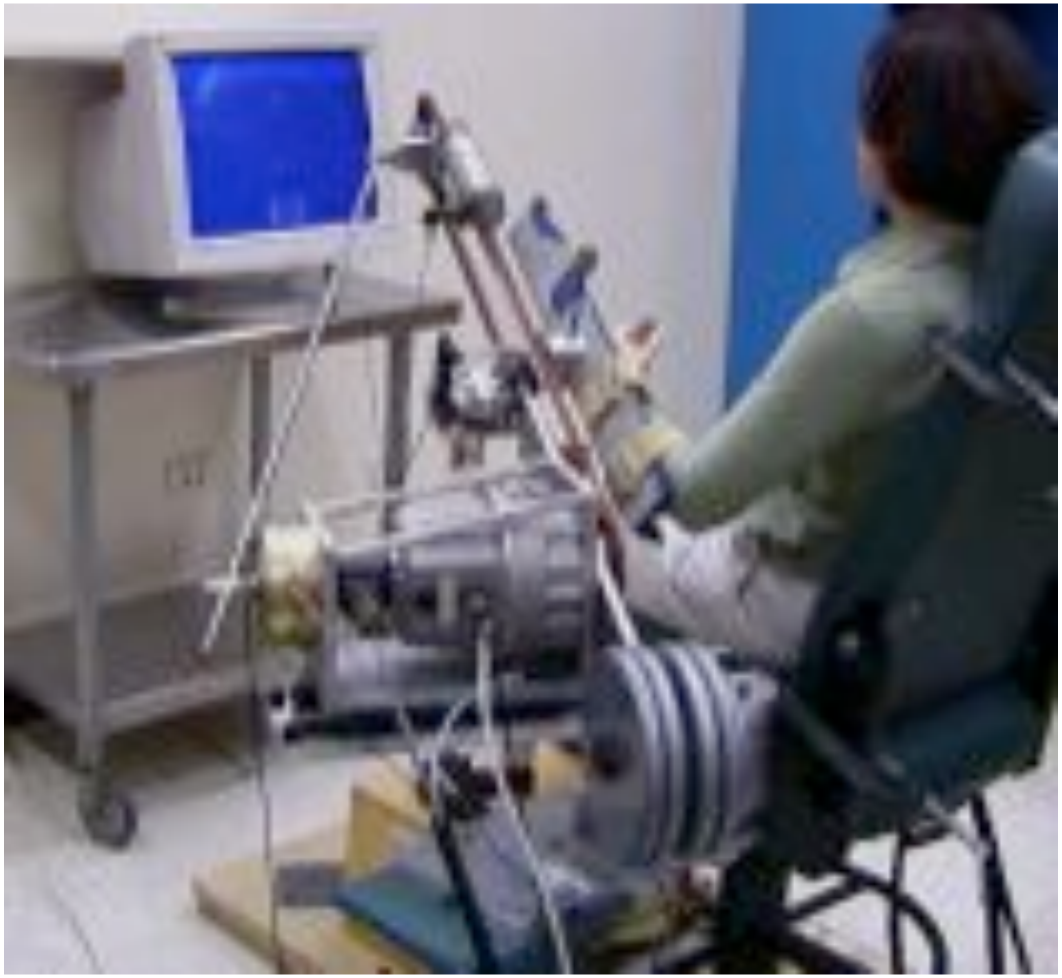
Fasoli et al. Effects of Robotic Therapy on Motor Impairment and Recovery in Chronic Stroke, *Arch. Phys. Medic. Rehab.* 84:477-482, 2003.

ARM Guide (Rehab Institute of Chicago)





Linear slide with motor
6-dof force sensing

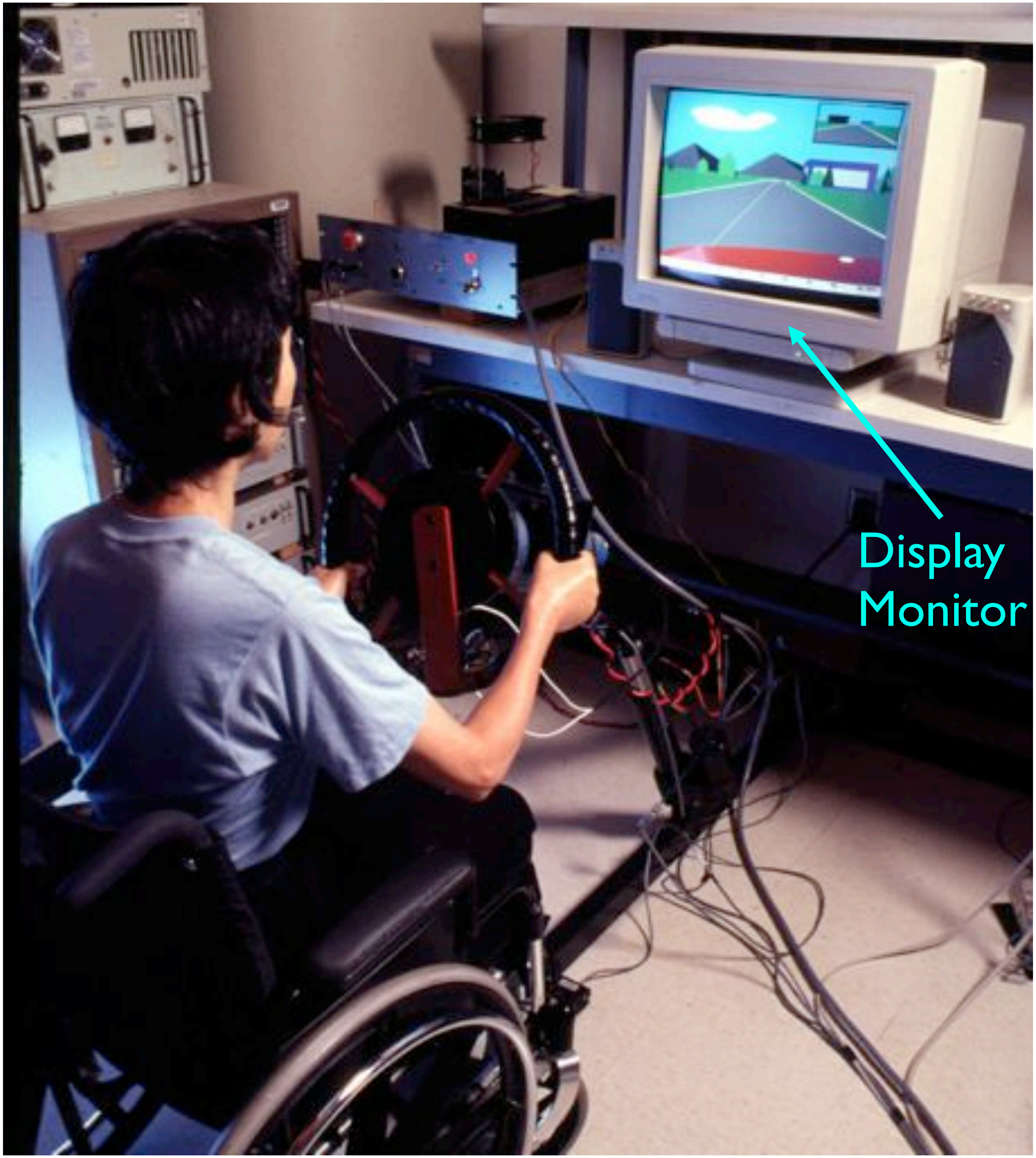


http://www.ric.org/research/centers/mars2/archives/mars-rerc/ARMGuide.aspx

Phase 2:
Augmenting the therapist

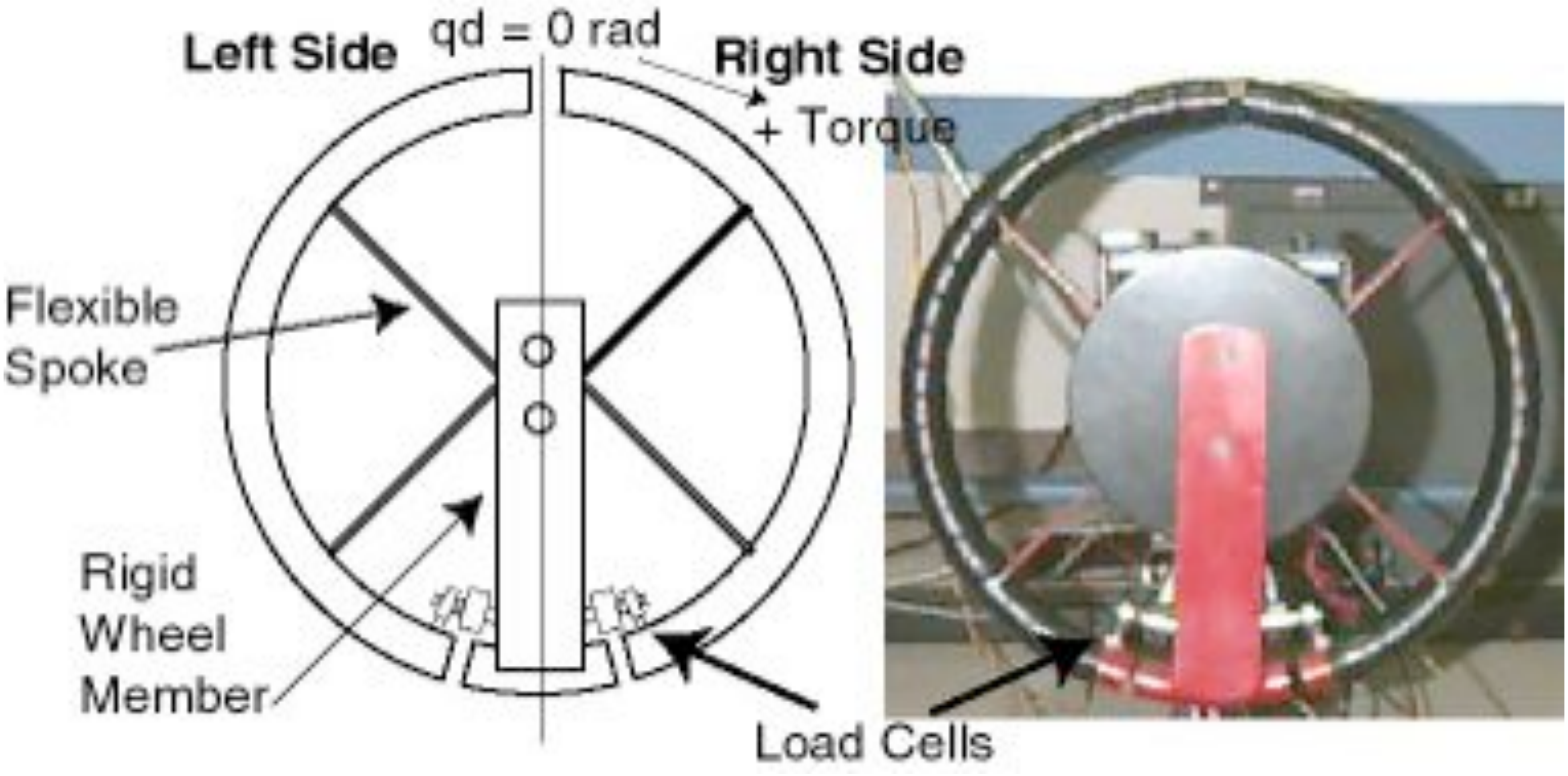
Driver's SEAT (PA VA/Stanford)

An upper limb one-degree-of-freedom robotic therapy device that incorporates a modified PC-based driving simulator.



Display Monitor

Split Steering Wheel



M.J. Johnson, H.F.M. Van der Loos, C.G. Burgar, P. Shor,. L.J. Leifer, Design and evaluation of Driver's SEAT: A car steering simulation environment for upper limb stroke therapy. *Robotica*, Volume 21, Issue 01. January 2003. pp. 13-23.

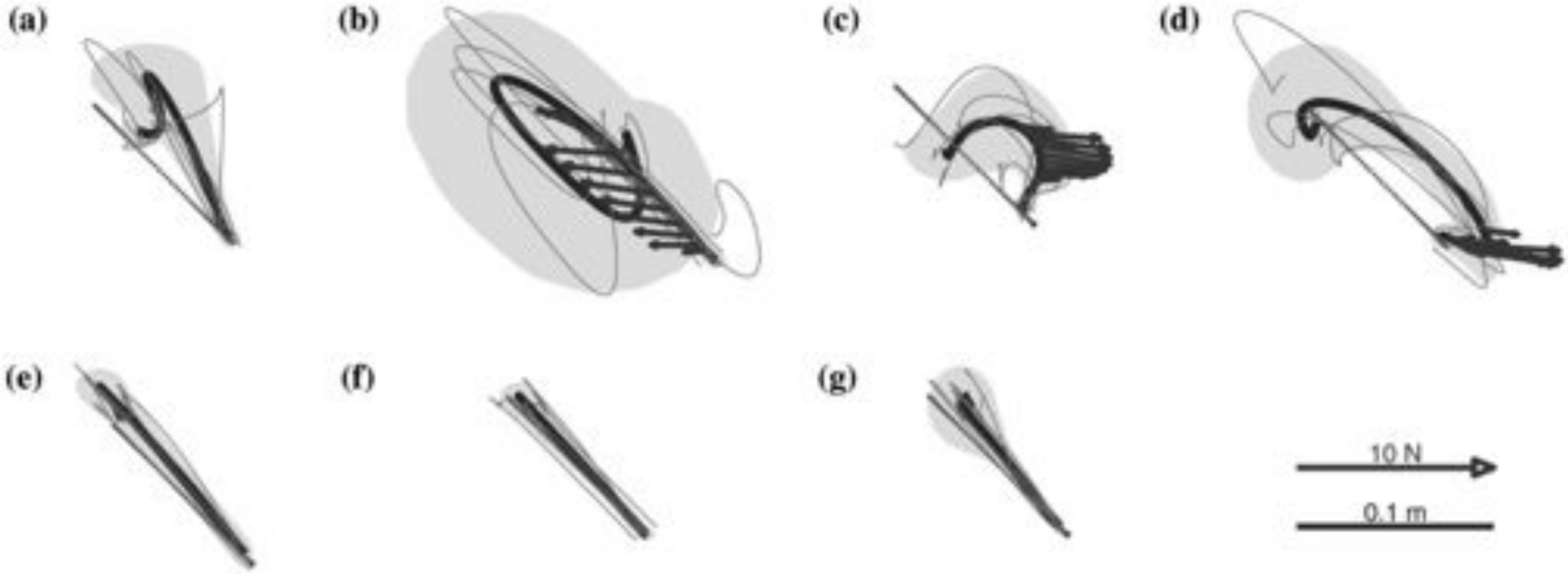
M.J. Johnson. H.F.M. Van der Loos, C.G. Burgar, P. Shor, L.J. Leifer, Experimental results using force-feedback cueing in robot-assisted stroke therapy, *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 13:3, Sept. 2005, pp. 335-348.

GENTLE/s (EU project)

P. van de Hel, B.J.F. Driessen, M.P. Oderwald, S. Coote, E. Stokes "Gentle/s: Robot mediated therapy for stroke patients in a virtual world makes exercising more enjoyable and effective," *Assistive technology - added value to the quality of life AAATE'01*, IOS Press Amsterdam C. Marincek et al. pp.256-261 (2001)

Phase 3:
Designing the super-therapist

Adding, then Removing Force-Field

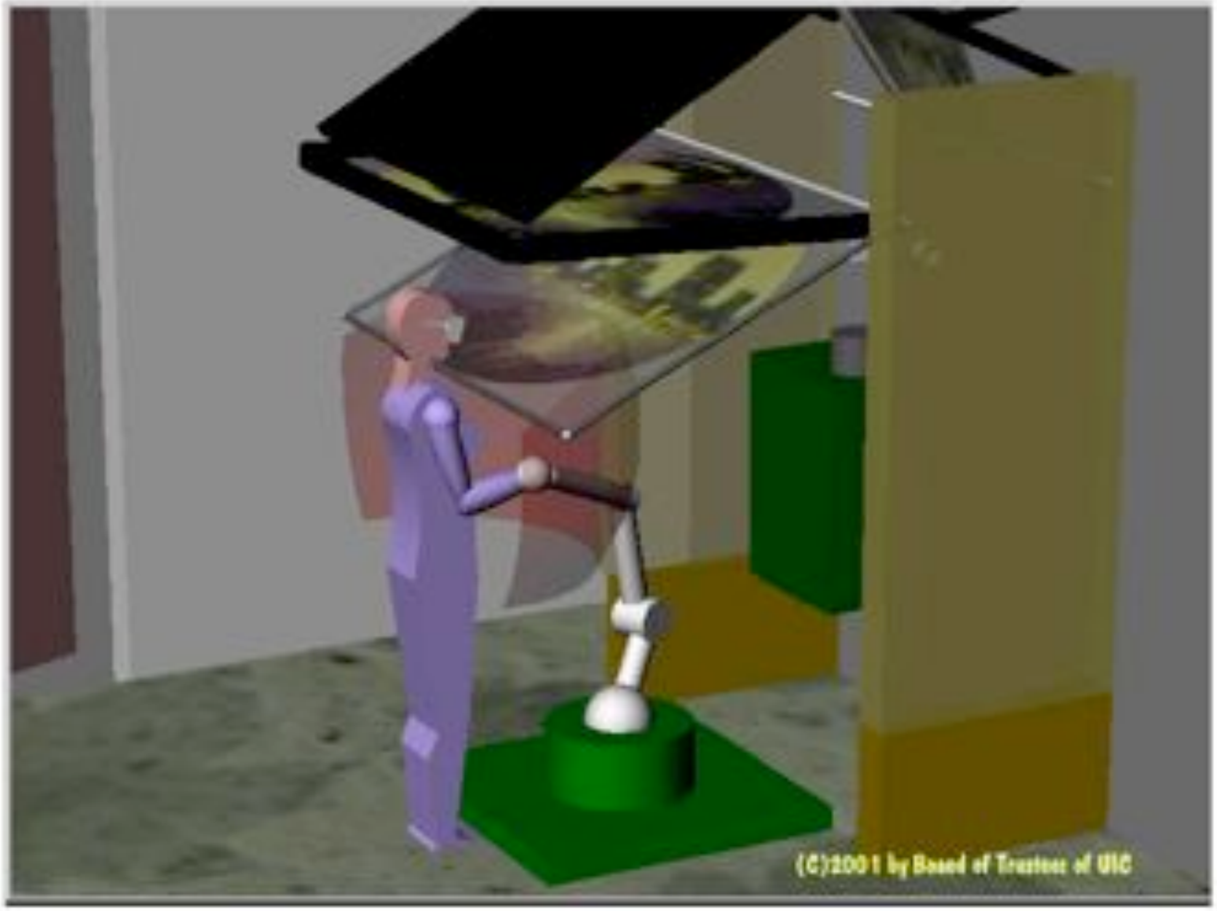


A 315° trajectory from one stroke subject. (a) unperturbed baseline, (b) late machine learning, (c) early training, (d) late training, (e) aftereffects, (f) early washout, and (g) late washout. Desired trajectories are bold dotted lines, average trajectories are bold solid lines, individual trajectories are thin lines, and shaded areas indicate running 95% confidence intervals of ensemble.

Patton JL, Kovic M, Mussa-Ivaldi FA. Custom-designed haptic training for restoring reaching ability to individuals with stroke, *Journal of Rehabilitation Research and Development* (JRRD), 43 (5), 2005, pp. 643-656.

‘Paris’ VR System (Rehab Institute of Chicago)

Goal: Better transfer to Activities of Daily Living



- 5-axis WAM manipulator
- Full-arm movement
- Projection of objects through glass
- Virtual object manipulation

http://www.smpp.northwestern.edu/robotLab/

Phase 4:
Enabling the inner therapist

Using affect to change robot behavior

Kulić, D., Croft, E.A., Affective State Estimation for Human–Robot Interaction, *IEEE Transactions on Robotics*, vol.23, no.5, pp. 991-1000, Oct. 2007.

Liu C, et al. Online Affect Detection and Robot Behavior Adaptation for Intervention of Children With Autism, *IEEE Transactions on Robotics*, vol.24, no.4, 883-896, Aug. 2008.

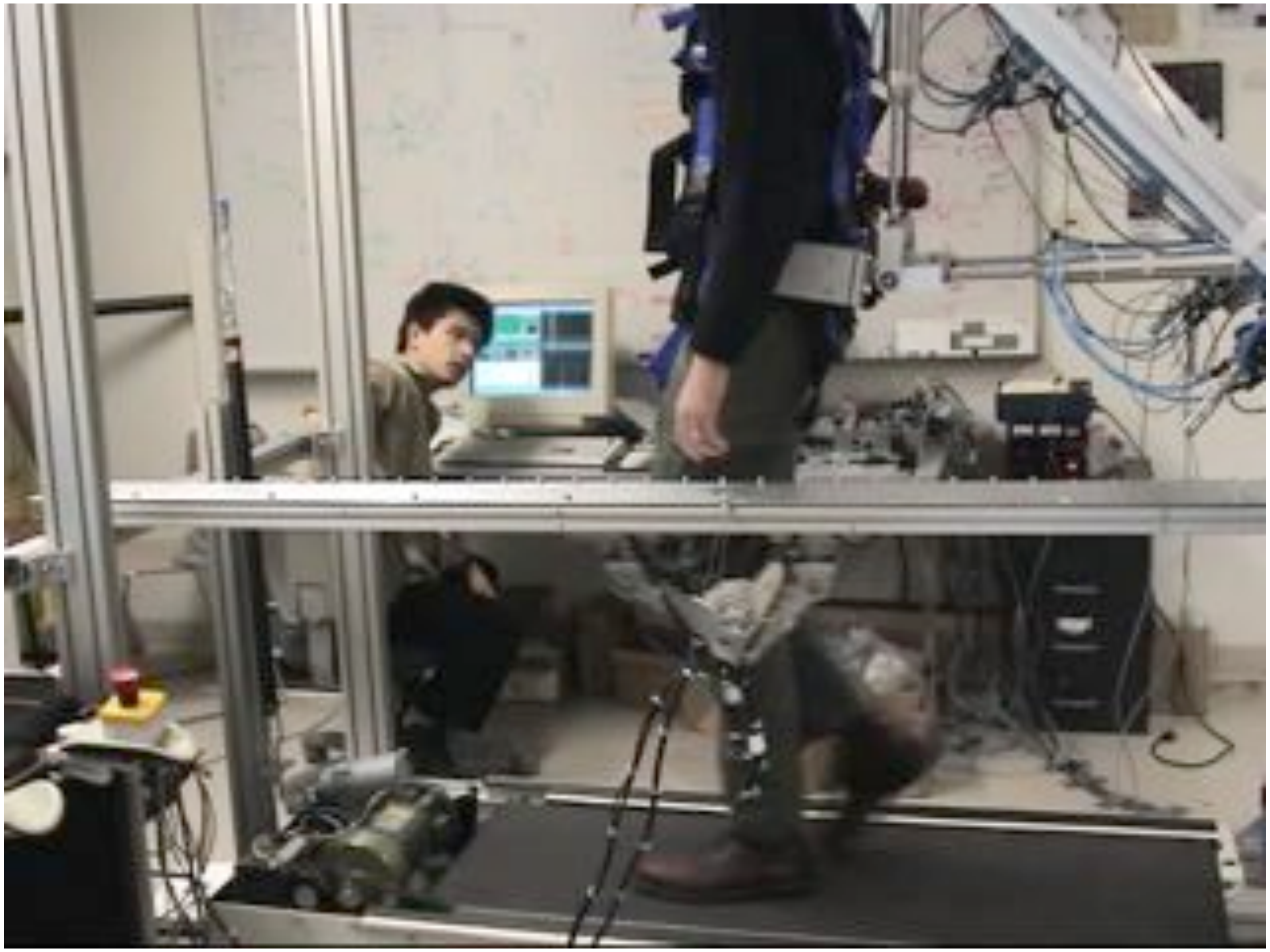
Novak, D., et al.Psychophysiological Responses to Robotic Rehabilitation Tasks in Stroke, *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol.18, no.4, pp. 351-361, Aug. 2010.

Riener, R., et al. Bio-cooperative robotics: controlling mechanical, physiological and mental patient states. Conference Proceedings IEEE 11th nternational Conference on Rehabilitation Robotics (ICORR 2009) , Kyoto, Japan, (2009)

Lower-Extremity Rehabilitation Robots

PAM + ARTHUR walking aid

- Treadmill-based
- Pelvis assist (PAM) + walking assist (ARTHUR)
- PAM: linear actuators to support pelvis
- Linear actuators on rail to provide foot motion assist



http://www.eng.uci.edu/~dreinken/Biolab/biolab.htm

Lokomat Treadmill Walker

- Each side = 2 dof
- Linear actuators
- Supported treadmill walking
- Patients with stroke, iSCI

http://www.research-projects.unizh.ch/med/unit43000/area198/p1237.htm

UBC-CARIS Lab Balance Training

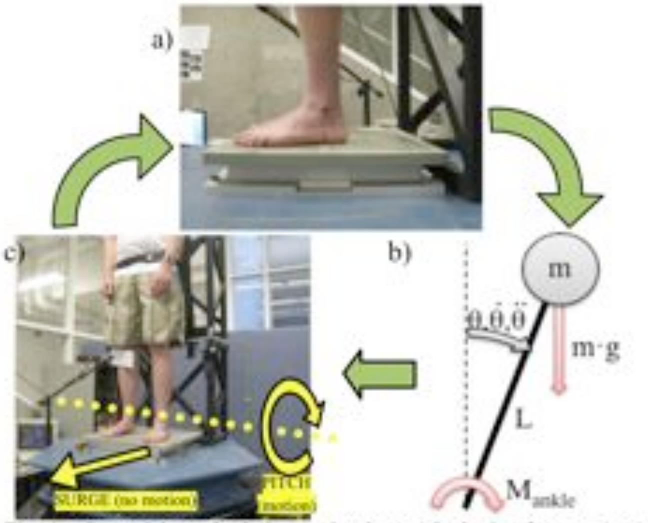
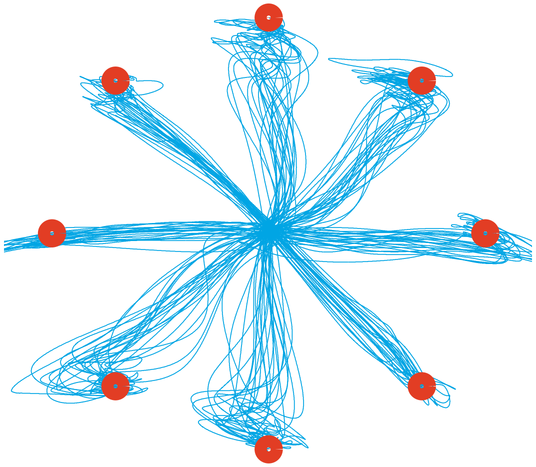


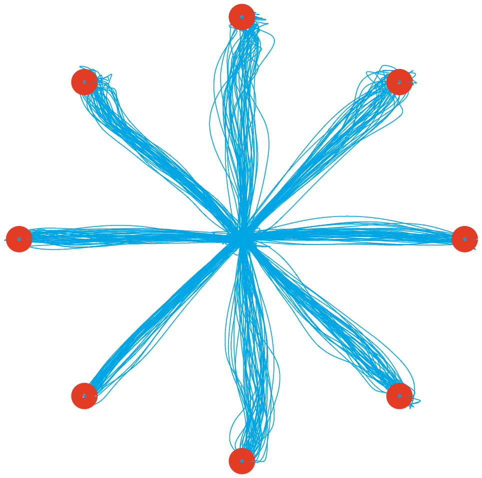
Fig. 1. Control loop for balance simulator (clockwise from top): a) forceplate measures ankle torque applied by subject; b) a computer calculates motion and position of an inverted pendulum with the same torque applied; c) the motion platform moves in pitch direction to match the position of the inverted pendulum; control loop repeats as subject moves with platform and adjusts ankle torque.

B. Luu, T. Huryn, E.A. Croft, H.F.M. Van der Loos, J.-S. Blouin, Investigating load stiffness in quiet stance using a robotic balance system, IEEE TNSRE, Apr. 2011.

T.P. Huryn, B.L. Luu, H.F.M. Van der Loos, J.-S. Blouin, E.A. Croft, Investigating human balance using a robotic motion platform, *Proceedings IEEE-ICRA 2010*, Anchorage, AL, May, 2010.

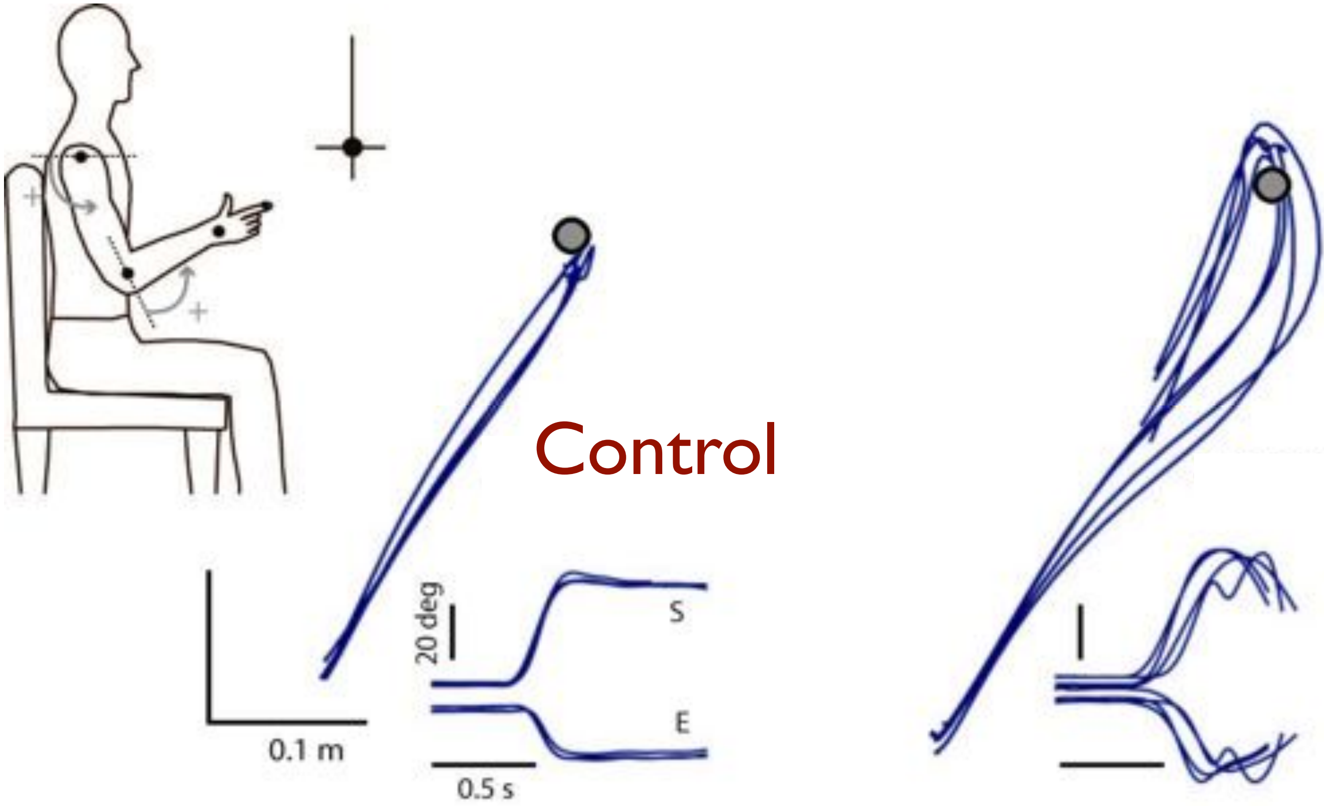
A case study: Compensation for cerebellar injury





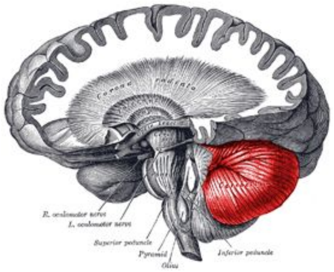
Allison Okamura (Stanford, JHU), in collaboration with:
Amy Bastian (JHU and KKI), David Grow (NMT),
and Nasir Bhanpuri (JHU)

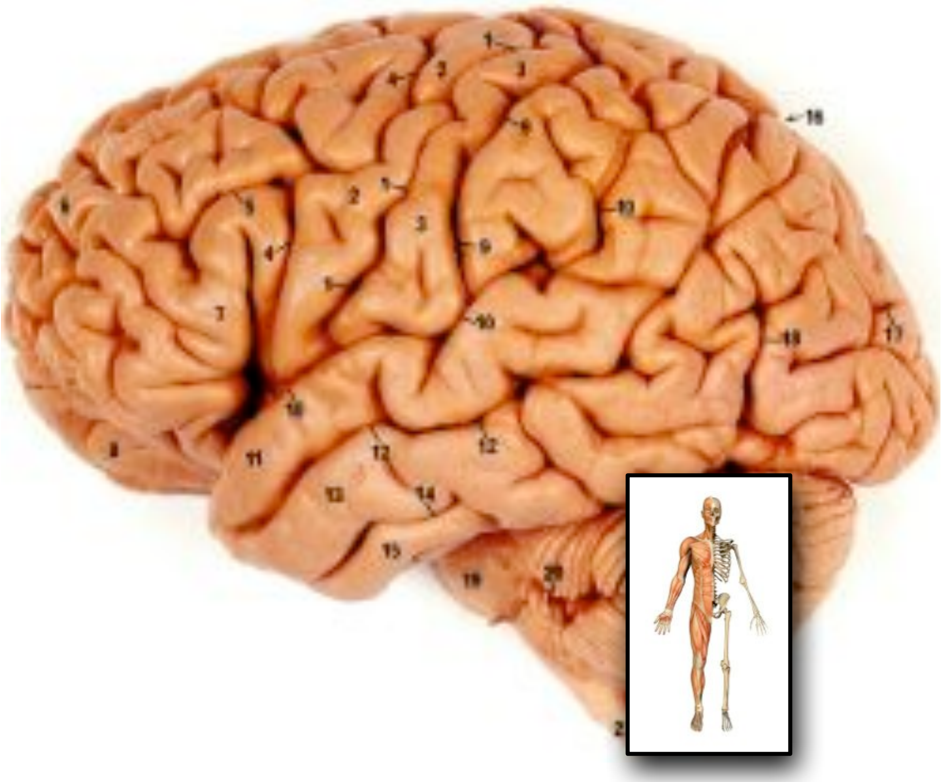
Motion Incoordination: Cerebellar Ataxia



Control

Cerebellar





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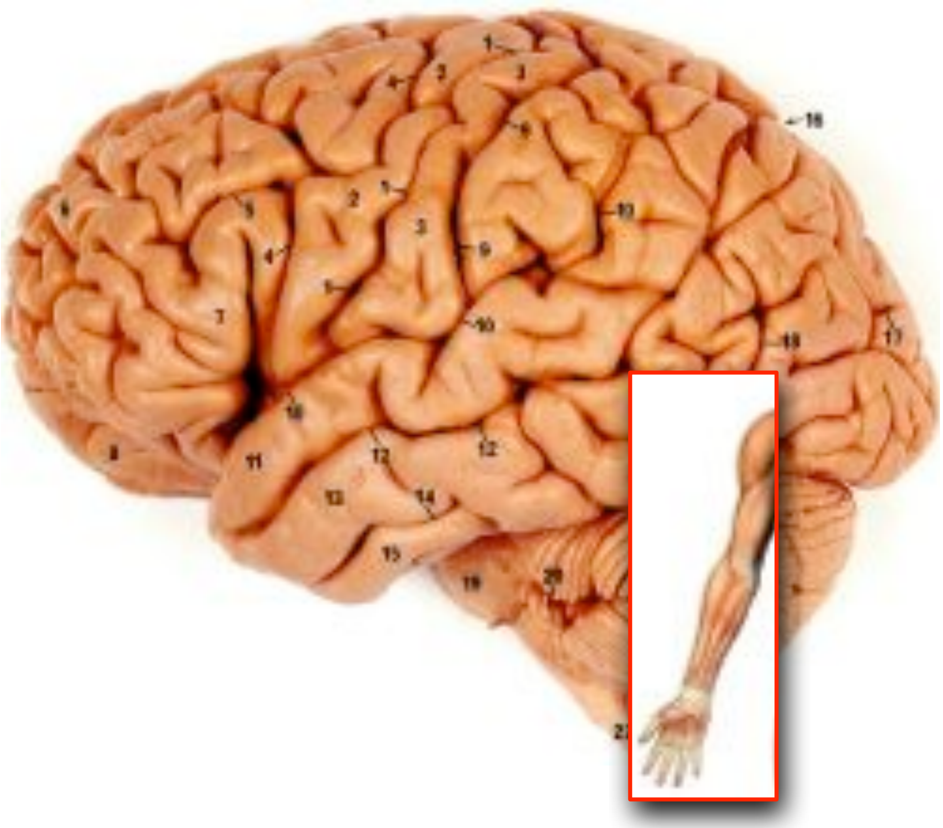
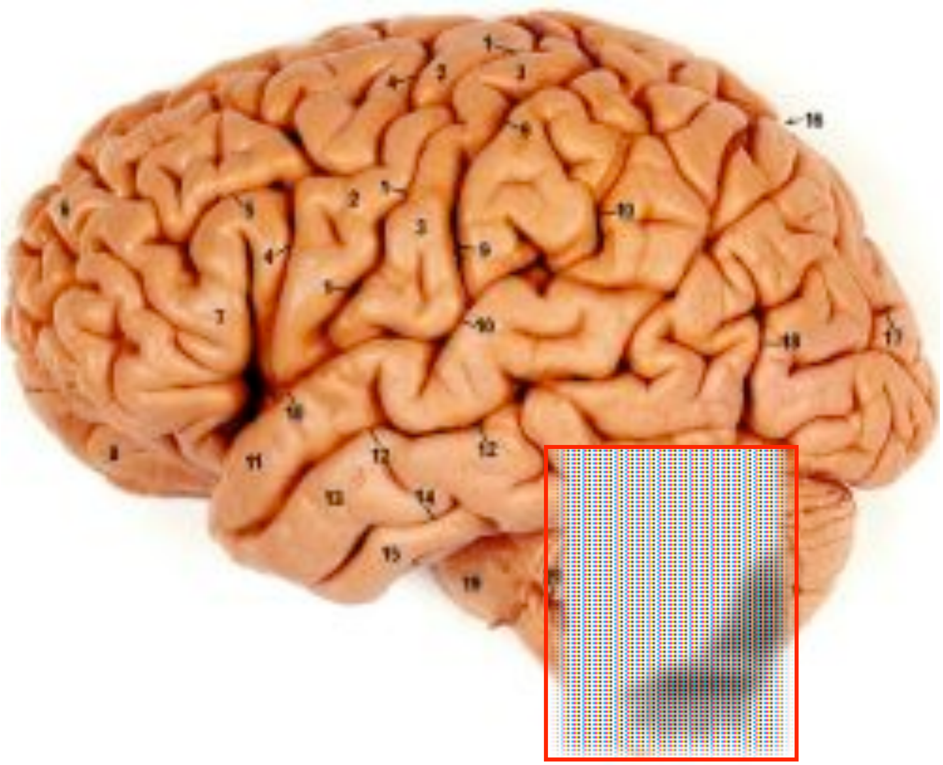
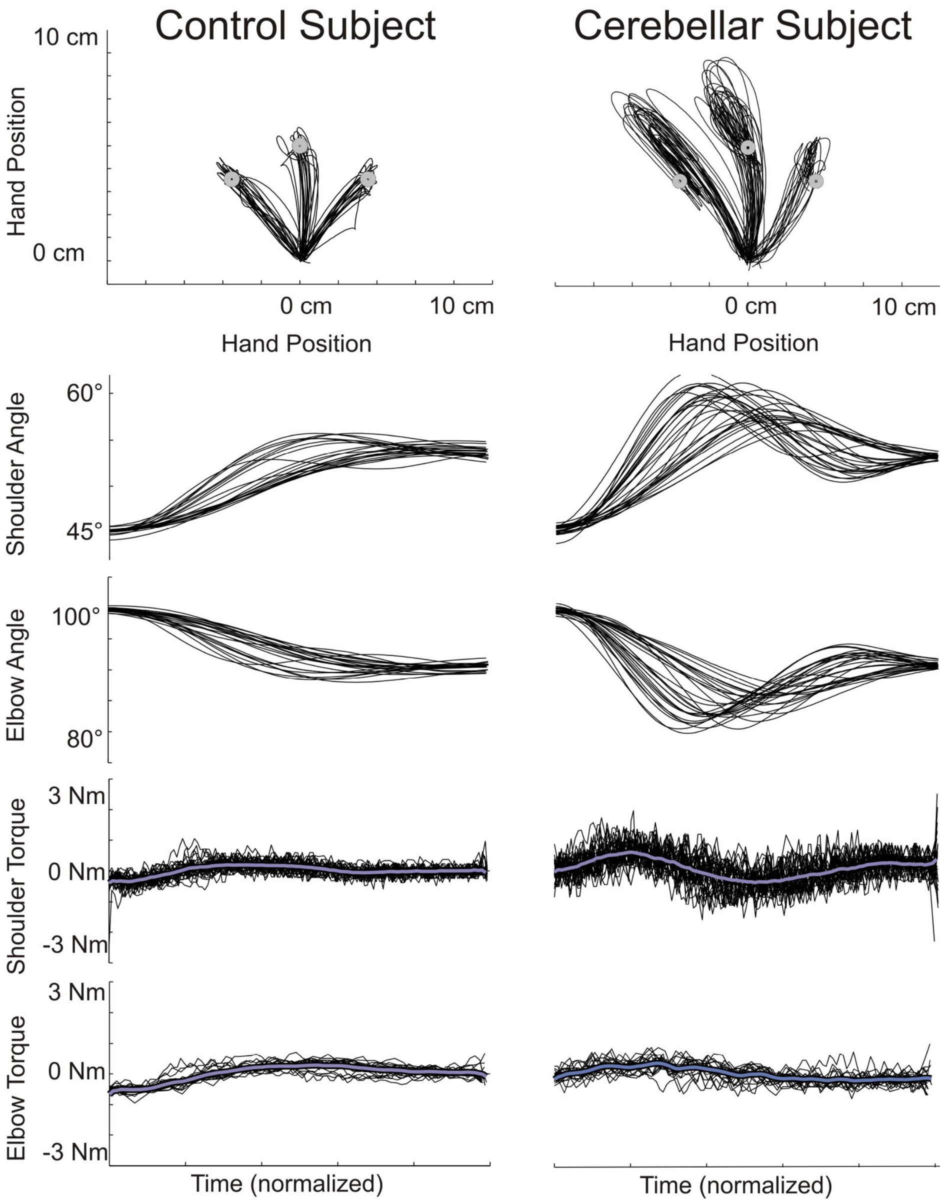


Bias

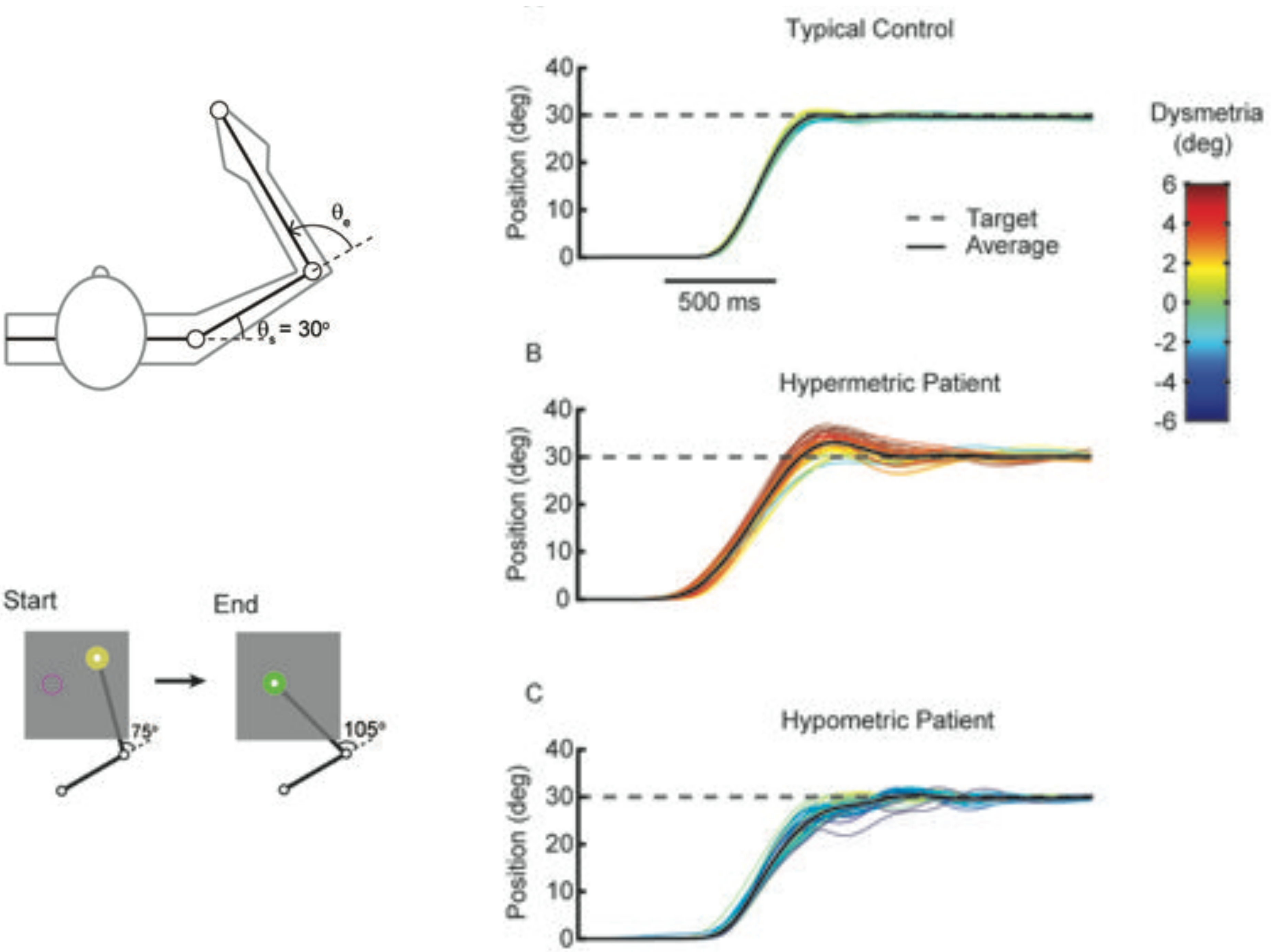


Variability

Measurement system



KINARM exoskeleton robot


θe
θs = 30°
Start
75°
End
105°
Typical Control
Position (deg)
40
30
20
10
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Target
Average
500 ms
Dysmetria (deg)
6
4
2
0
-2
-4
-6
B
Hypermetric Patient
Position (deg)
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30
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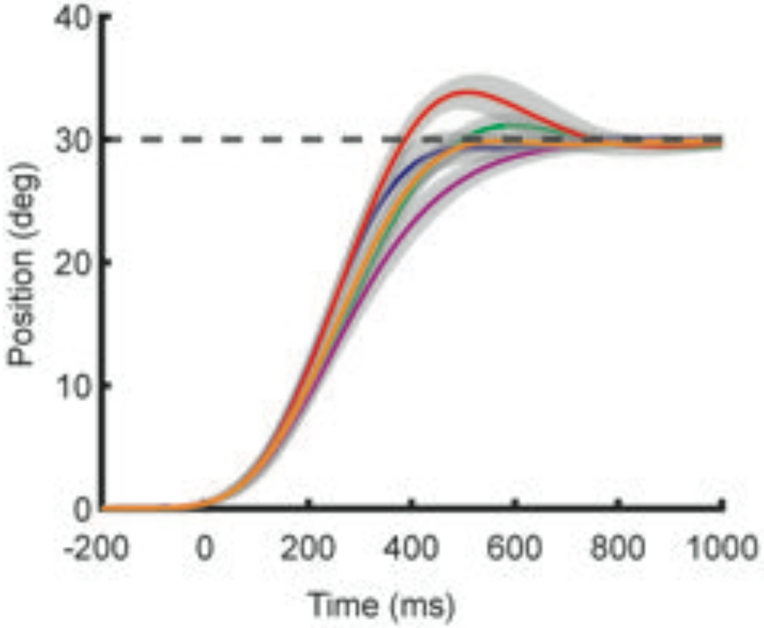
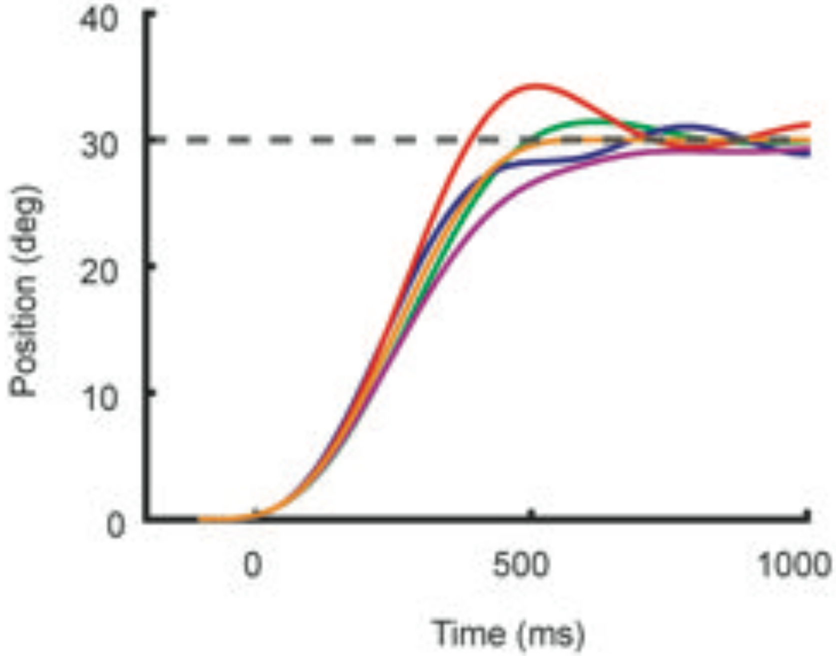
10
0
C
Hypometric Patient
Position (deg)
40
30
20
10
0

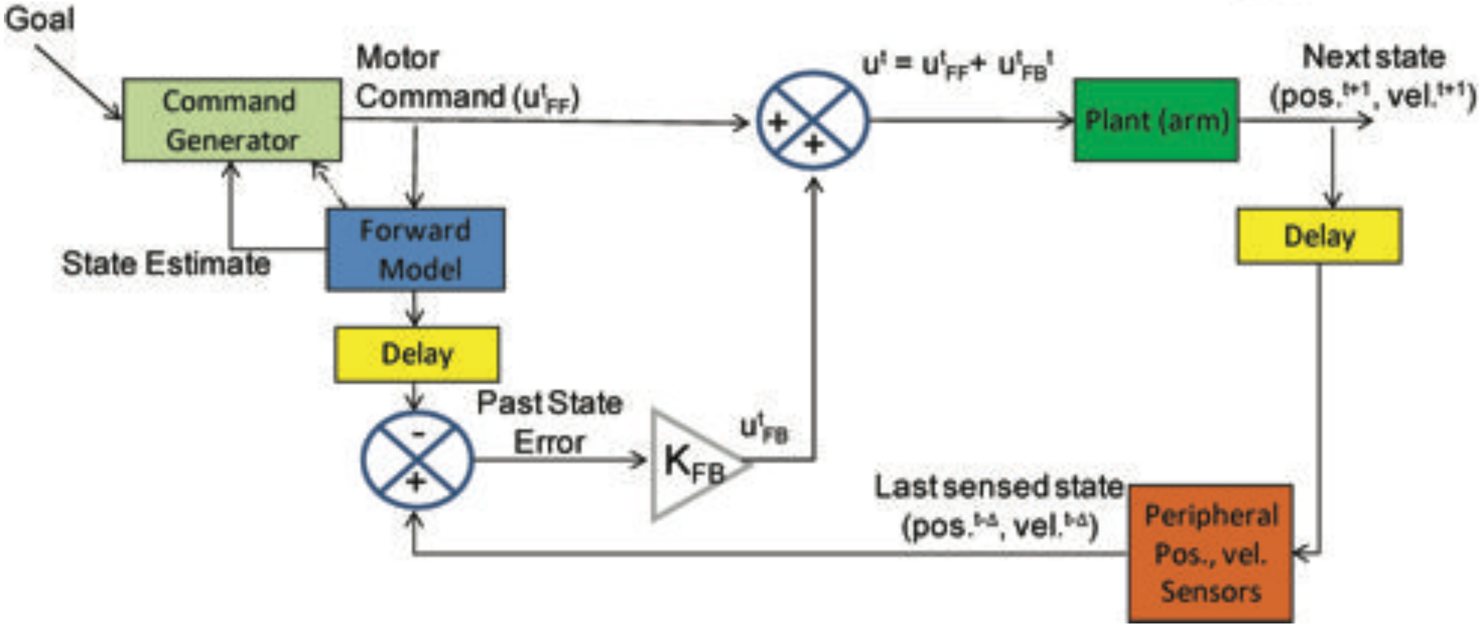
control perturbations



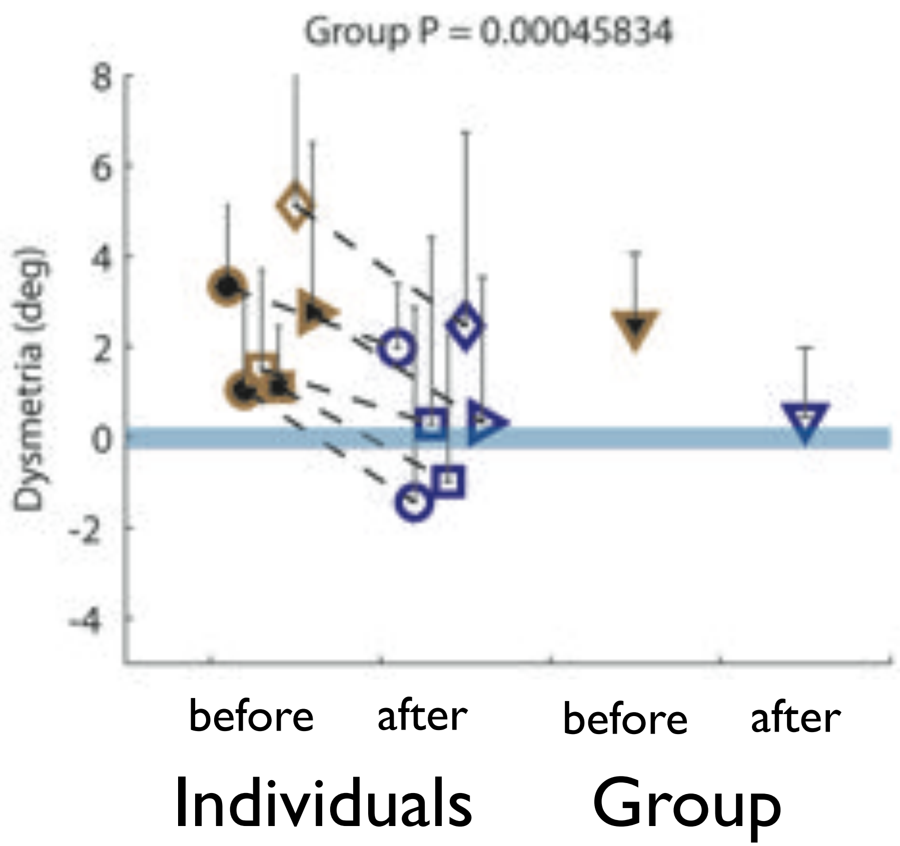
model



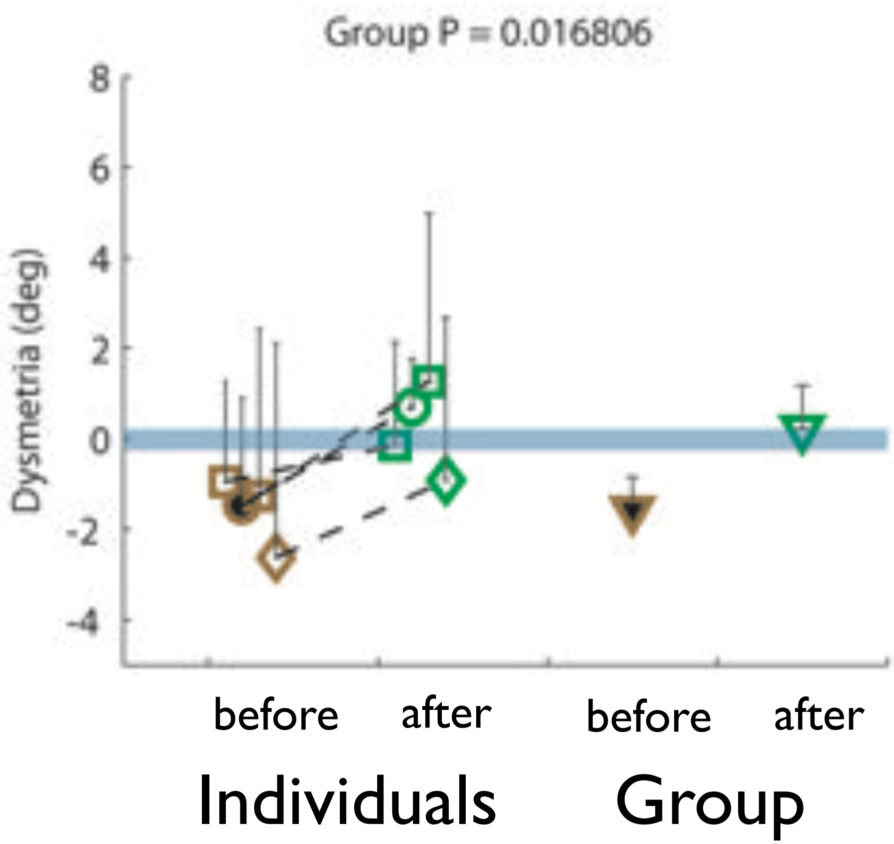
🟧 Baseline
🟩 Increased Inertia
🟦 Decreased Inertia
🟪 Increased Viscosity
🟥 Decreased Viscosity
- - Target



If a patient has **hypermetria**,
use the robot to
decrease their inertia



If a patient has **hypometria**,
use the robot to
increase their inertia



What does this mean?

We find patient specific biases in dynamics representation.

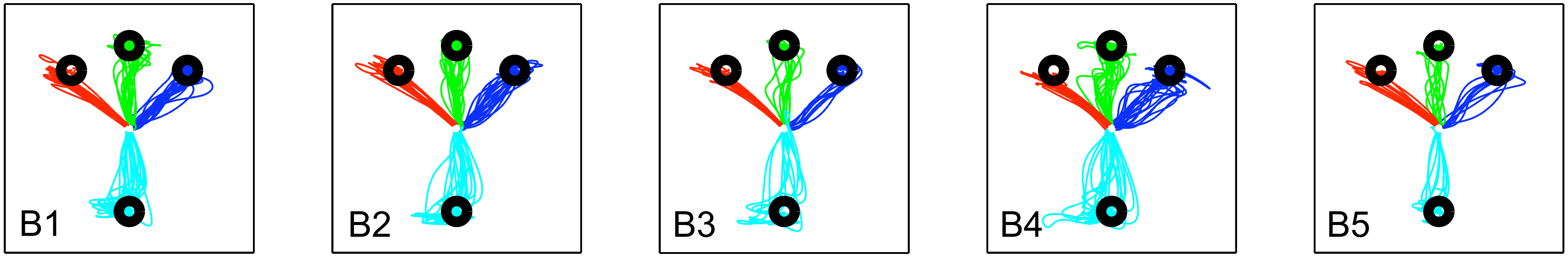
We can replicate by creating a mismatch
in control dynamics (inertia) and using simulation.

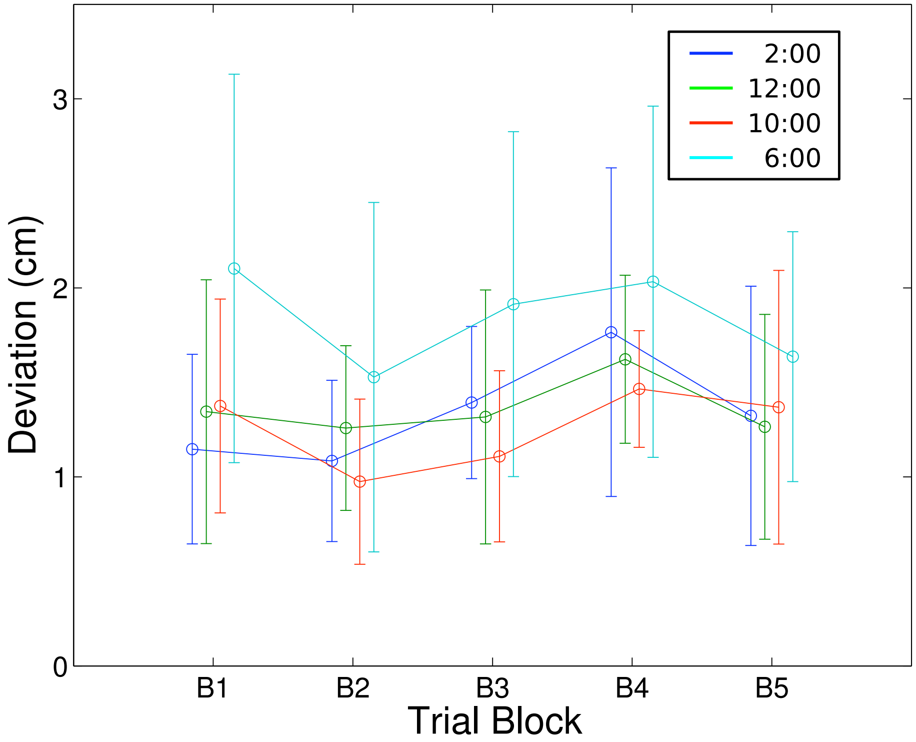
We can partially correct by altering patient limb inertia with a robot.

This does not correct trial-to-trial variability.

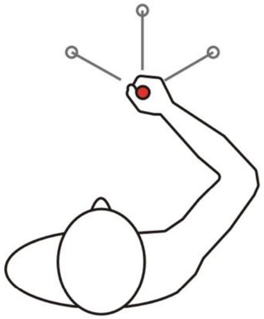
What about planar reaching?

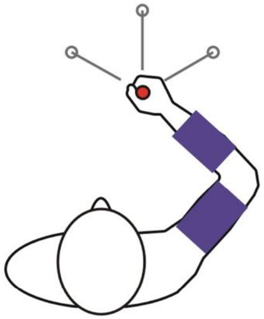
null field | compensation (helping) | null field | compensation (worsening) | null field

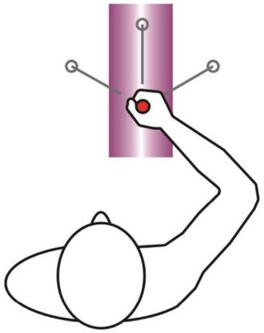


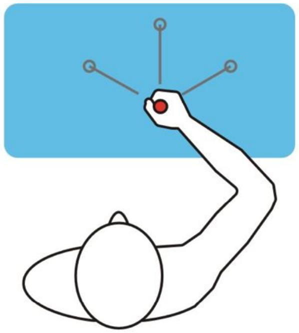


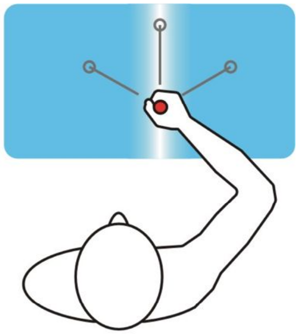
Compensation and Adaptation

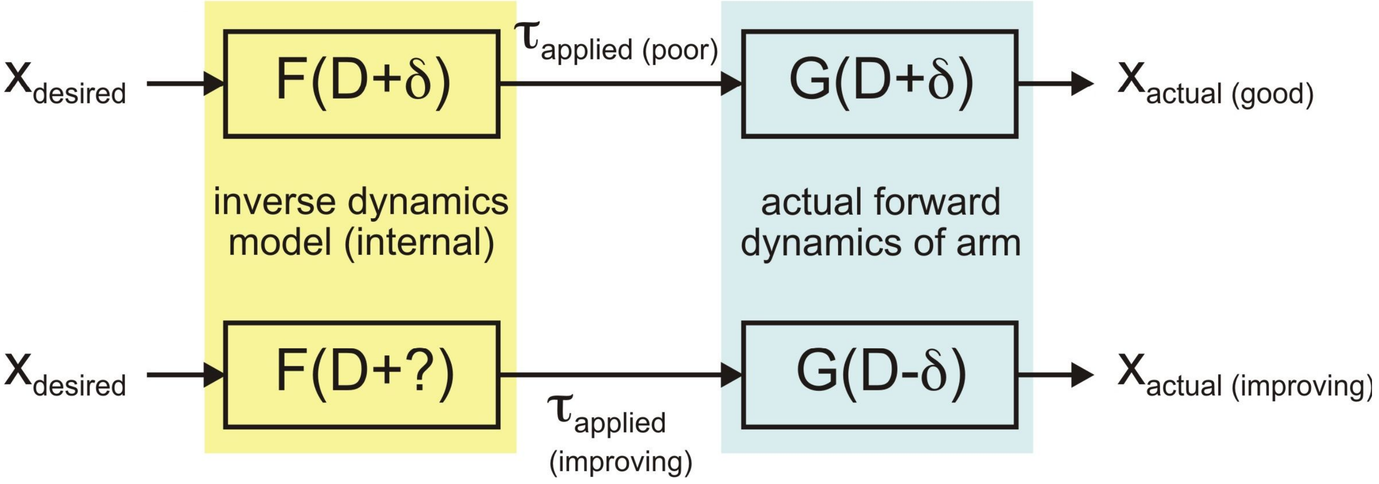

no compensation


inertia compensation


force channel


viscous damping


pseudo-adittance



Compensation: $x_{desired}$ → $F(D+\delta)$ → $\tau_{applied\ (poor)}$ → $G(D+\delta)$ → $x_{actual\ (good)}$

inverse dynamics model (internal)

actual forward dynamics of arm

Adaptation: $x_{desired}$ → $F(D+?)$ → $\tau_{applied}$ (improving) → $G(D-\delta)$ → $x_{actual\ (improving)}$

In an ideal world, medical robotics includes:

- Quantitative descriptions of patient state
- Use of models to plan intervention
- Design of devices, systems, and processes to connect information to action (= robotics)
- Incorporating human input in a natural way
- Goal: improve health and quality of life

But these are only the *technical* challenges...

Growing Healthcare Challenges

Regaining function & retaining independence

Caretaking for staying at home/aging–in-place

Individualized learning and training for special needs

Millions suffer from isolation and depression

6.6M special ed students

3.5M children with ADHD

1 in 5 children is overweight

1M Parkinson's patients,
50,000 new/year
750,000 strokes/year in US alone

Vets with PTSD, TBI, amputations, etc.

A surging need for caregivers in-home and in-institution

6.2 to 7.5M people with mental retardation

Maja Mataric (USC)

Socially Assistive Robotics

Problem: cost/population size and growth trends
Need: personalized medium to long-term care
Part of the solution: human-centered robotics to improve health outcomes

- Monitoring
- Coaching/training
- Motivation
- Companionship/socialization

Maja Mataric (USC)

Movement Therapy and Assistance

- Over 25% of U.S. population has some functional physical limitation that affects normal living
- 6.5M people in the US have had a stroke (by 2050, cost projected to be $2.2 Trillion)