Robotics in Stroke Recovery

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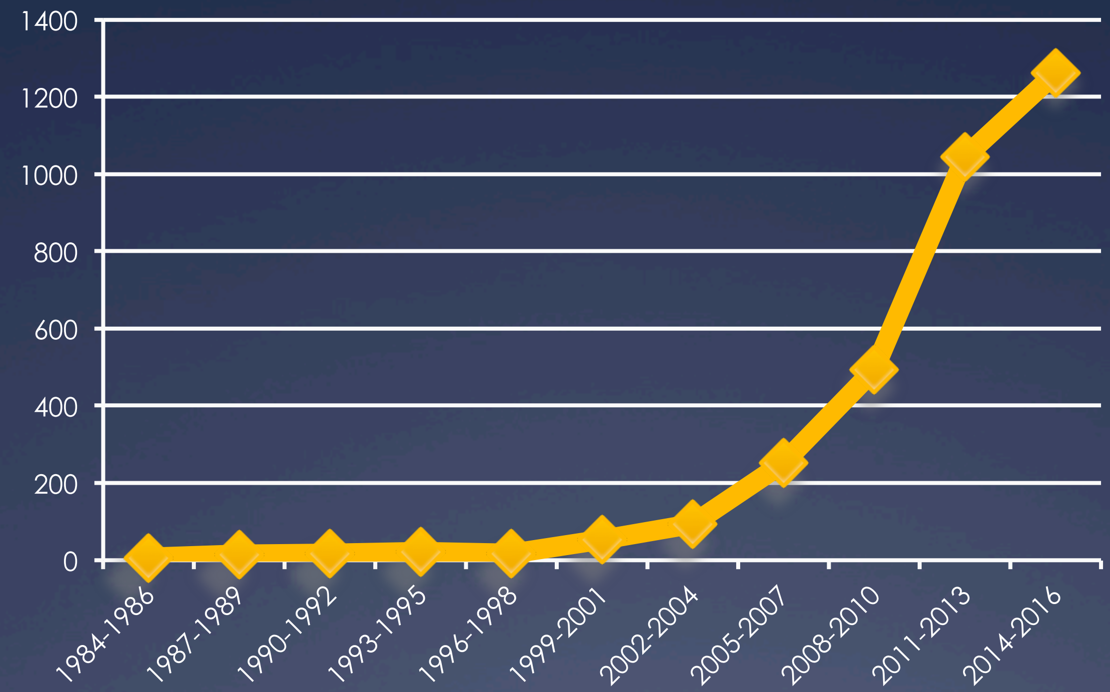
Disclosures

* Funded Research
  * Nexstim - clinical trial
* Consulting - Tyromotion

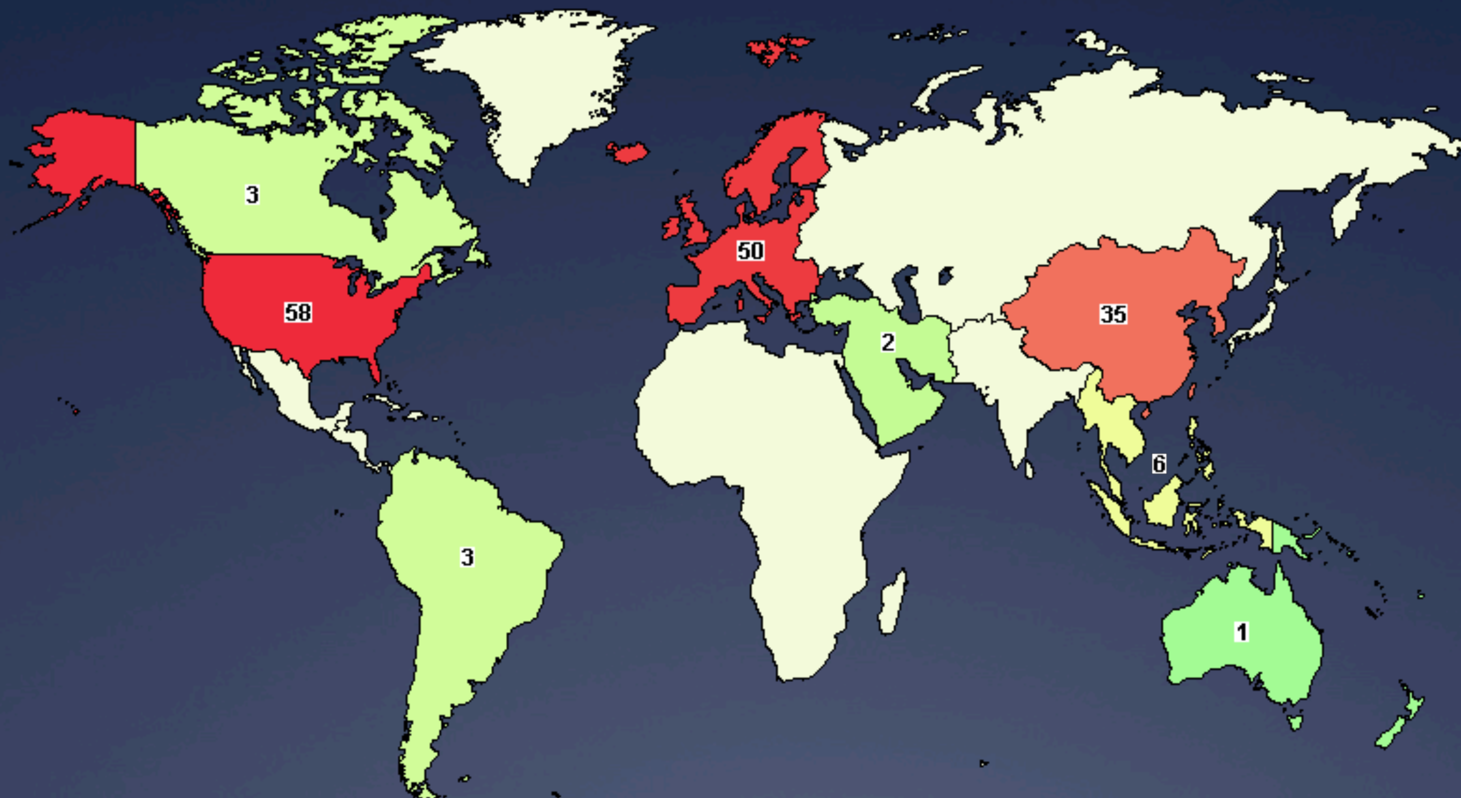
Objectives

- Rationale for robot-aided rehabilitation
- Barriers to adoption of robots in clinical practice
- Where are we now in adopting rehabilitation Robotics?
- Identify strengths and limitations of current robotic technologies
- Propose strategies to facilitate clinical integration of robots in rehabilitation

Rehabilitation Robotics Publications



Rehabilitation Robotics Clinical Trials



From Clinicaltrials.gov on 5/26/17, all studies, n=165.
57 trials currently open

Upper-Limb Commercially Available Robots in US

- Workstation
  - Amadeo (Tyromotion)
  - Armeo Power (Hocoma)
  - Armotion (Reha Technology)
  - Hand Mentor Pro (Motus Nova)
  - Hand of Hope (Rehab-Robotics)
  - Inmotion Arm (Bionik)
  - Inmotion Wrist (Bionik)
  - Inmotion Hand (Bionik)
  - Kinarm (BKIN)
  - Proficio (Barrett)
  - ReoGo (Motorika)
- Robot-ish
  - Diego (Tyromotion)
  - Armeo Boom and Spring (Hocoma)
- Wearable
  - MyoPro (Myomo)
- Wheelchair-mounted
  - Jaco (Kinova)
  - iARM (Exact Dynamics)

Lower-Limb Commercially Available Robots in US

* Workstation
  * G-EO (Reha Technology)
  * KineAssist-MX (HDT Global)
  * Lokomat (Hocoma)
  * Walkbot (P&S Mechanics)
* Wearable
  * Bionic Leg (AlterG)
  * eLegs (Ekso Bionics)
  * Indego (Parker-Hannifin)
  * ReWalk (ReWalk Robotics)
  * Rex (Rex Bionics)

But Slow Adoption

Bionik Laboratories Reaches Milestone with Shipment of 250th Interactive Robotic Therapy System for Patient Rehabilitation

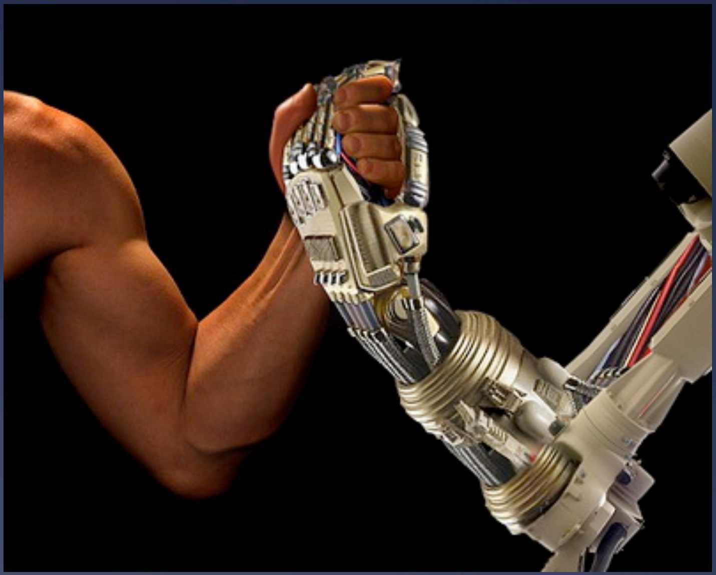
APRIL 25, 2017

DOWNLOAD AS PDF

Proposed Robot Applications

- Exercise training devices for hemiparesis
  - Upper Limbs
  - Lower Limbs
- Wearable powered braces for daily use
- ADL assistance for profoundly disabled
- Social/Telepresence robots

Advantages of Robotic Exercise Training?



Avoiding Therapist Fatigue

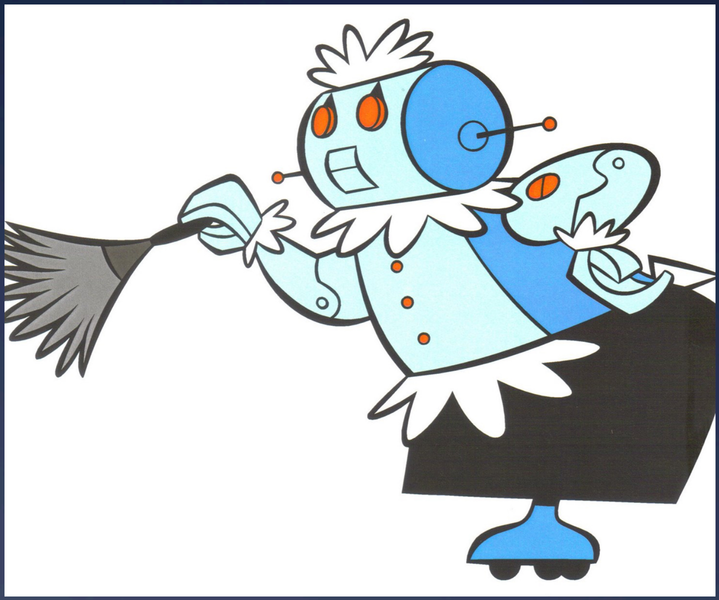
* CPM for knee replacement as a (non-robotic) example

Engage the patient

- More interesting for the patient

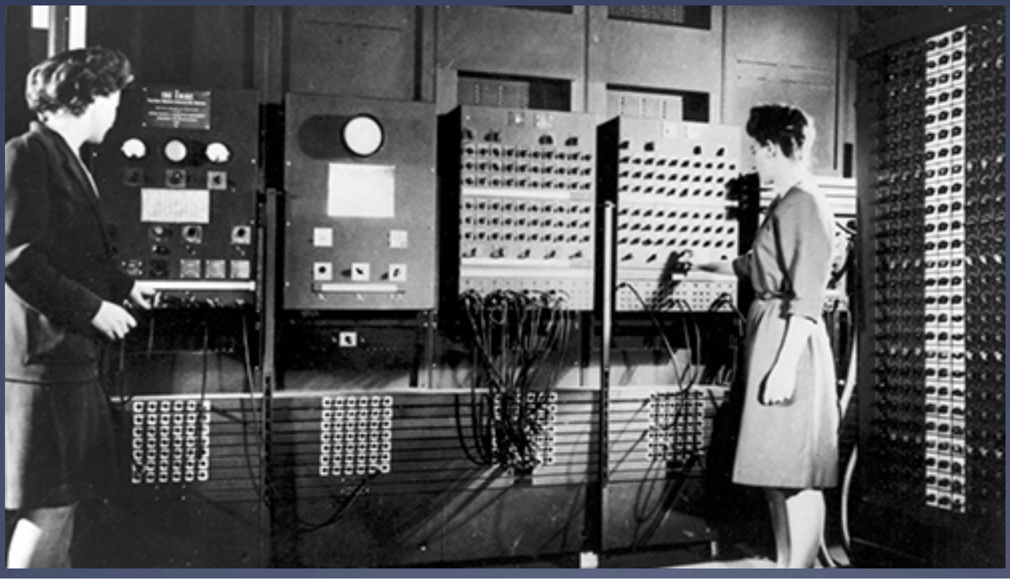
Proposed Cost Savings

* Cost (Labor) savings
  * Deliver same therapy with fewer staff
  * Deliver more therapy without increasing staff
* Cost of personnel is rising while the cost of technology is falling
* 1:1 Model: Most common currently – a staff member is present supervising the session as his/her only activity. No labor savings achieved.
* Robotic gym model: One staff member supervising multiple patients



Economic barriers

- Costs of devices are high, useful life is short
- Devices consume a lot of space
- Devices remain highly specialized, and limited in ability to truly substitute for human therapy
- Complexity of devices generally requires direct supervision of therapy sessions, reducing (or eliminating) labor savings



Eniac with programmers

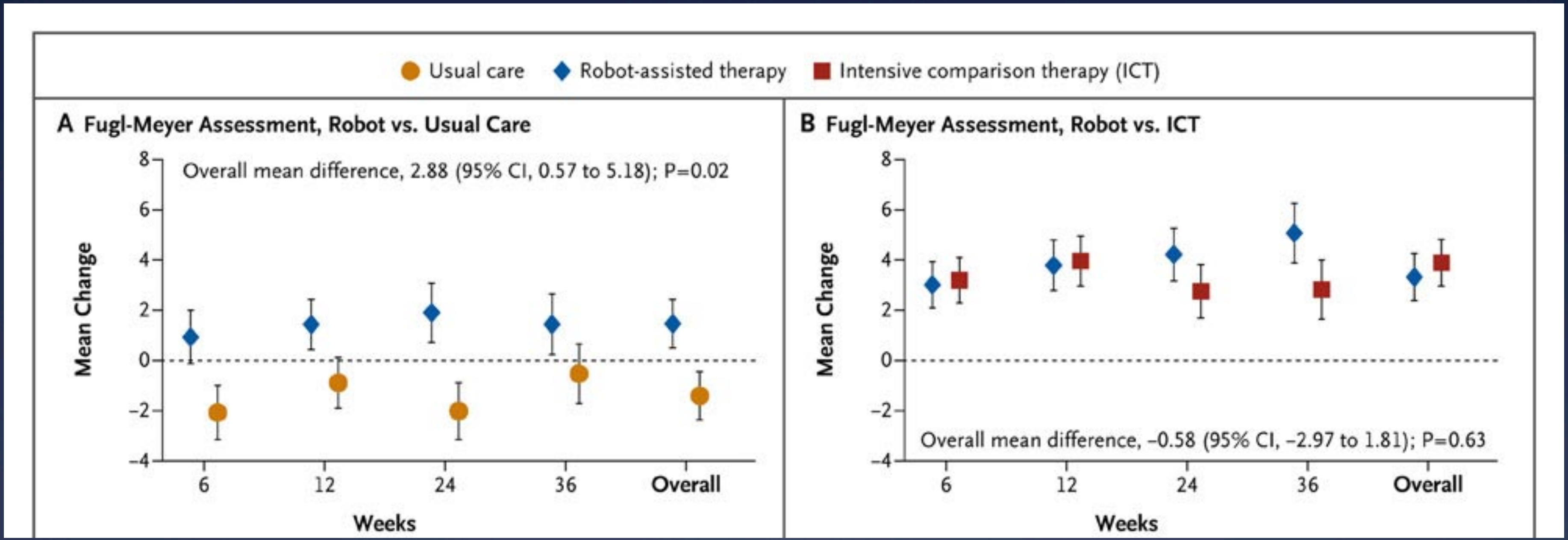
Can Robots Provide More Effective Therapy than Humans?

* More repetitions than human therapy
* Greater consistency of treatment
* Potentially could provide more effective treatment algorithm than human therapists (not yet convincingly demonstrated)

Optimizing control and training algorithms

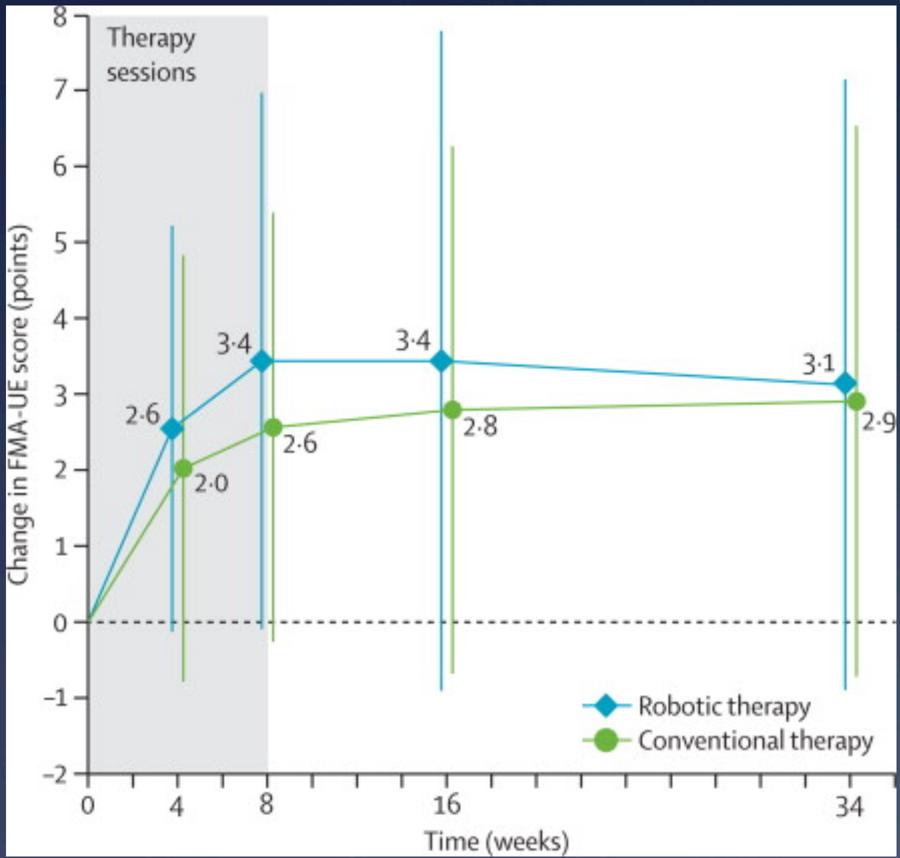
* Many devices provide "assist as needed", but unclear if this is optimal.
* Underlying concept is essentially Hebbian training – that successful execution of a motor task reinforces the underlying neural pathway
* Other strategies might include error augmentation, resisting the desired movement to make the task harder to accomplish, or inducing adaptation (e.g. pushing a hemiparetic patient towards their unaffected side).
* Encouraging mirrored movements – good or bad for recovery? Or perhaps both (at different stages of recovery)?

Efficacy: VA Robot Study



Lo A et al. N Engl J Med 2010;10.1056/NEJMoa0911341

ARMin study



- Randomized controlled trial
- Robotic vs. dose-matched conventional therapy
- N=73
- Chronic hemiparesis (> 6 months)
- 24 sessions over 8 weeks

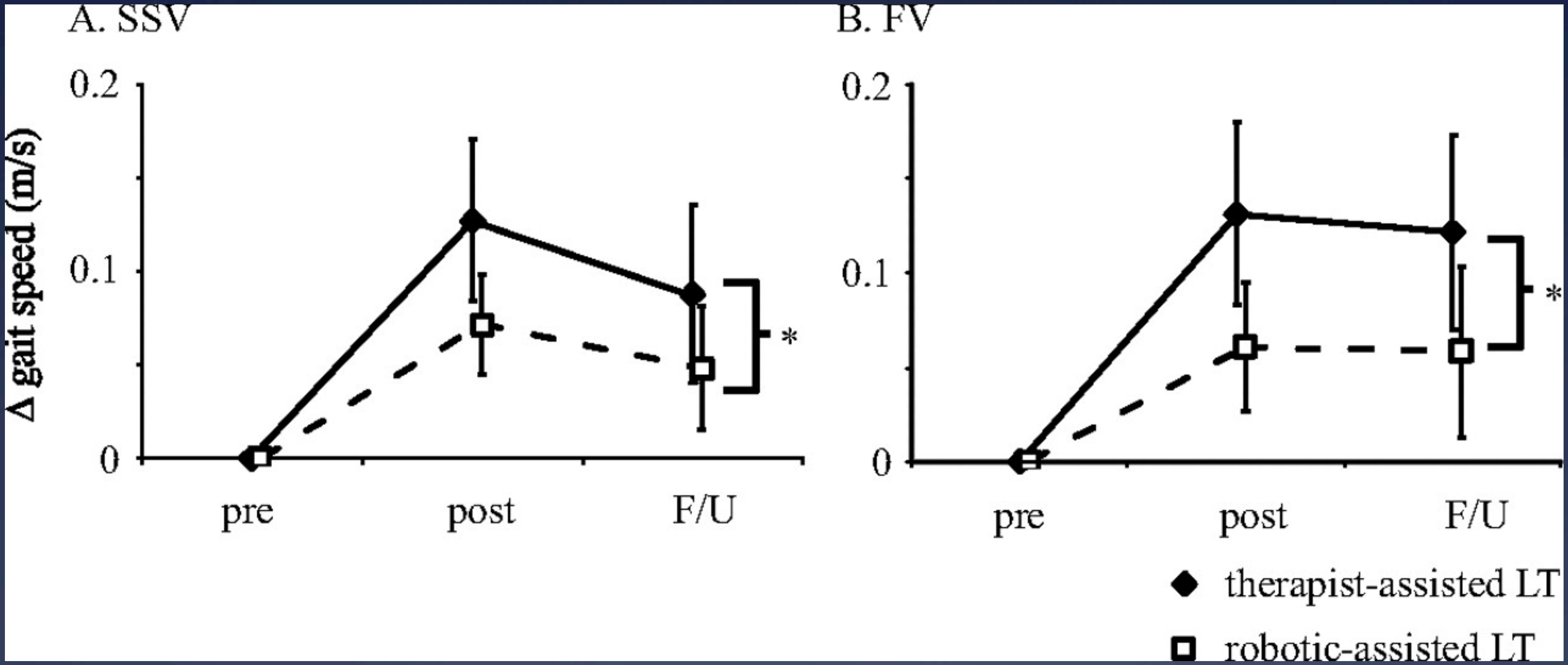
Change in FMA-UE score from baseline Error bars are SD. FMA-UE=arm (upper extremity) section of Fugl-Meyer assessment.

Verena Klamroth-Marganska , Javier Blanco , Katrin Campen , Armin Curt , Volker Dietz , Thierry Ettlin , Morena F et al. **Three-dimensional, task-specific robot therapy of the arm after stroke: a multicentre, parallel-group randomised trial.** The Lancet Neurology, Volume 13, Issue 2, 2014, 159 - 166

Robotic Efficacy?

* Improvements for upper limb robotic therapy generally in the 2-5 point range on the UEFM
* Comparable to gains seen with other forms of exercise therapy post-stroke
* VA robotic study found no difference between robotic therapy and human-delivered therapy; ARMin study showed slight advantage for robotic therapy
* Evidence for superiority of robotic therapy is lacking

Robotic (Lokomat) vs. Human Gait training



Changes in gait speed at post- and F/U assessments at self-selected velocity (SSV; A) and fast velocity (FV; B)

Hornby, T. G. et al. Stroke 2008;39:1786-1792

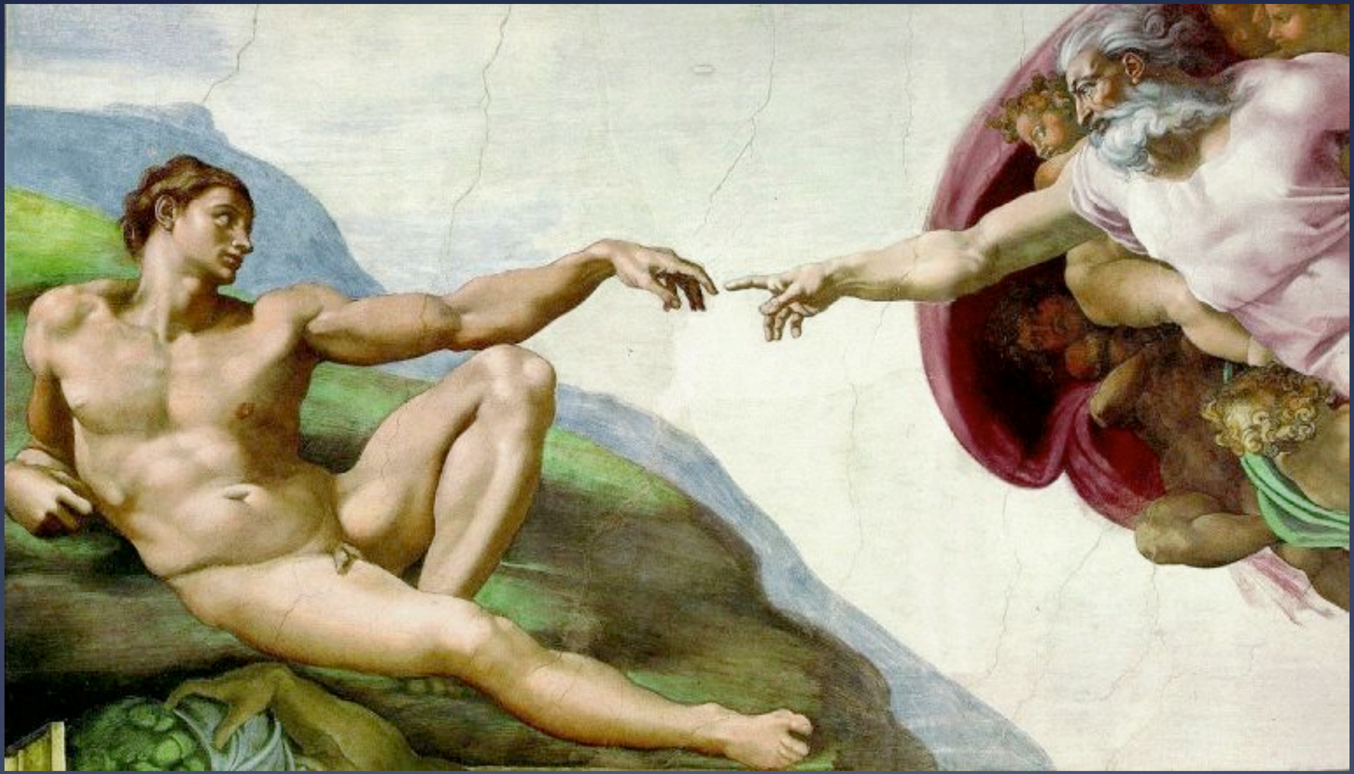
Upper vs. Lower Limb Robotics?

Upper Limb	**Lower Limb**
Movement path variable	Movement path predictable
Movements typically non-rhythmic	Rhythmic
Typically poor functional outcome in stroke	Typically reasonable functional outcome in stroke
Some evidence suggests robotic therapy may be better than conventional exercise	No real evidence suggesting benefit over conventional exercise. LEAPS trial suggested little benefit to non-robotic locomotor training

Types of Exercise Robots

- By Type of Design:
  - Workstation – end effector (e.g. InMotion Shoulder-Elbow robot)
  - Workstation – cable driven (e.g. TPAD, Tyromotion Diego)
  - Workstation – exoskeletal (e.g. Lokomat, Armeo Power)
  - Wearable exoskeletal (e.g. AlterG Bionic Leg, Myomo)
    - Also used as wearable powered braces
  - Wearable soft devices
- By Limb(s) trained
  - Upper Limb
  - Lower Limb

End-Effector Robots



Fresco courtesy of Michaelangelo

MIT-Manus/InMotion Shoulder-Elbow Robot

G-EO

Exoskeletal Workstations

Photo courtesy of Hocoma

Armeo Power

Lokomat

Video courtesy of Hocoma, Inc.

Limitations of traditional workstation robots

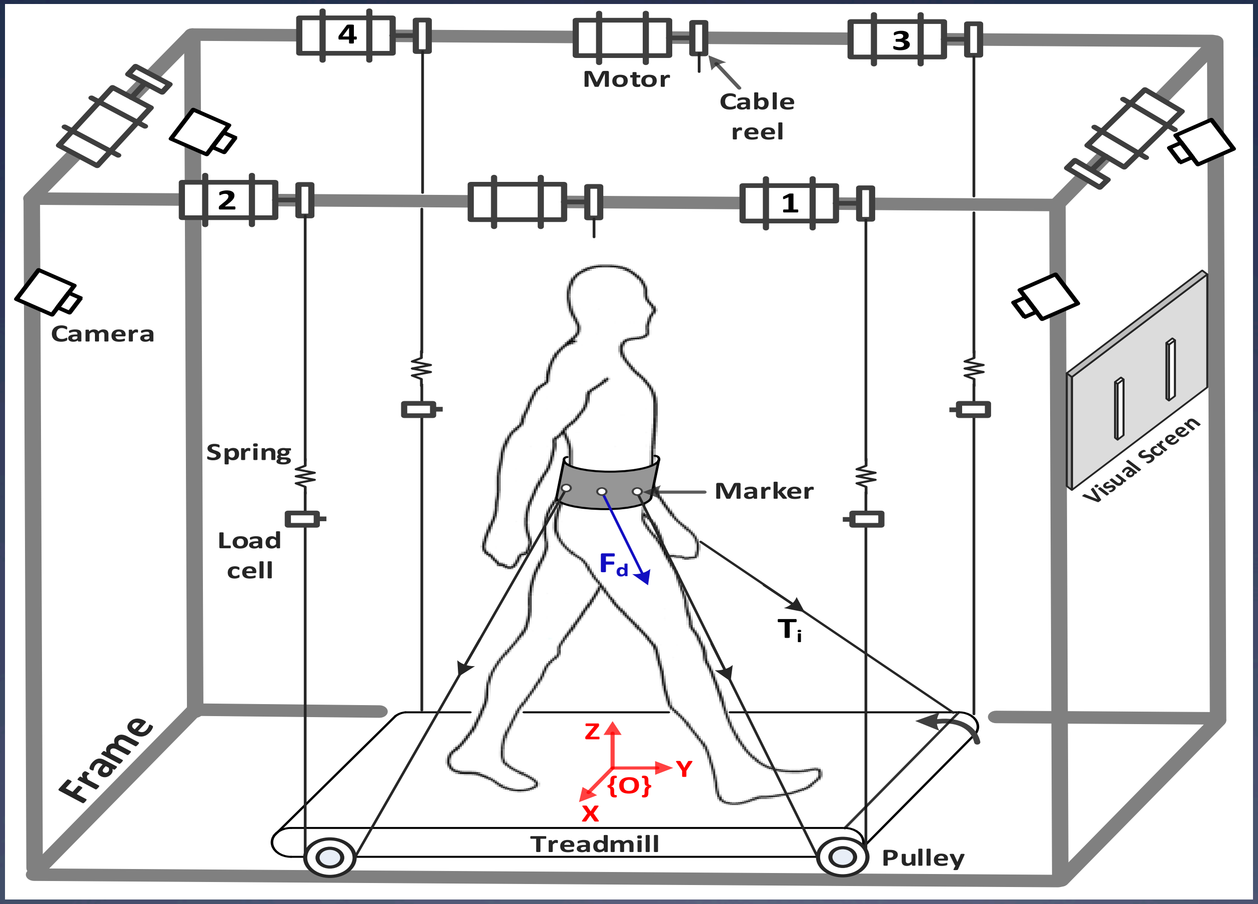
* Expensive
* Large/space consuming
* Substantial mass and inertia
* Lacks inherent compliance
* May be uncomfortable
* Not practical for home use
* Simulated functional tasks, rather than actual

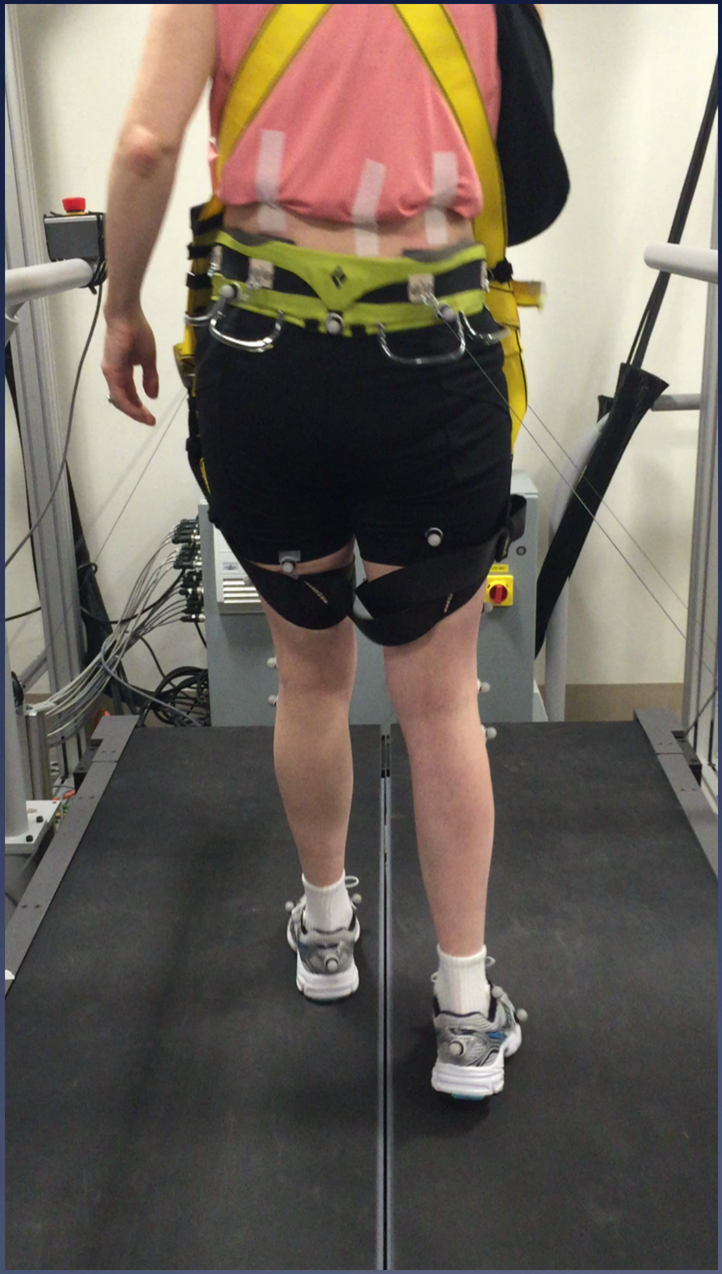
Cable-Driven Workstation

* Cables connected to limb segments, connected to actuator
* More control of segmental movement than end-effector
* Less restrictive and lighter weight than exoskeletal
* Requires frame to orient and guide cables, house actuators

Carex – Agrawal Lab

A-TPAD (Agrawal Lab)





Tyromotion Diego

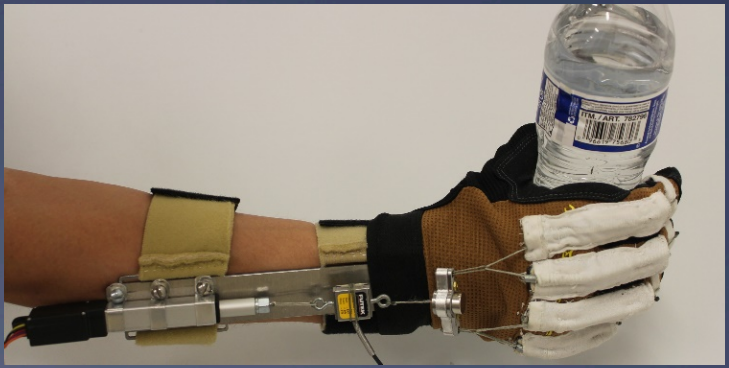
Photo and Video courtesy of Tyromotion

Cable-Driven Workstation Robots

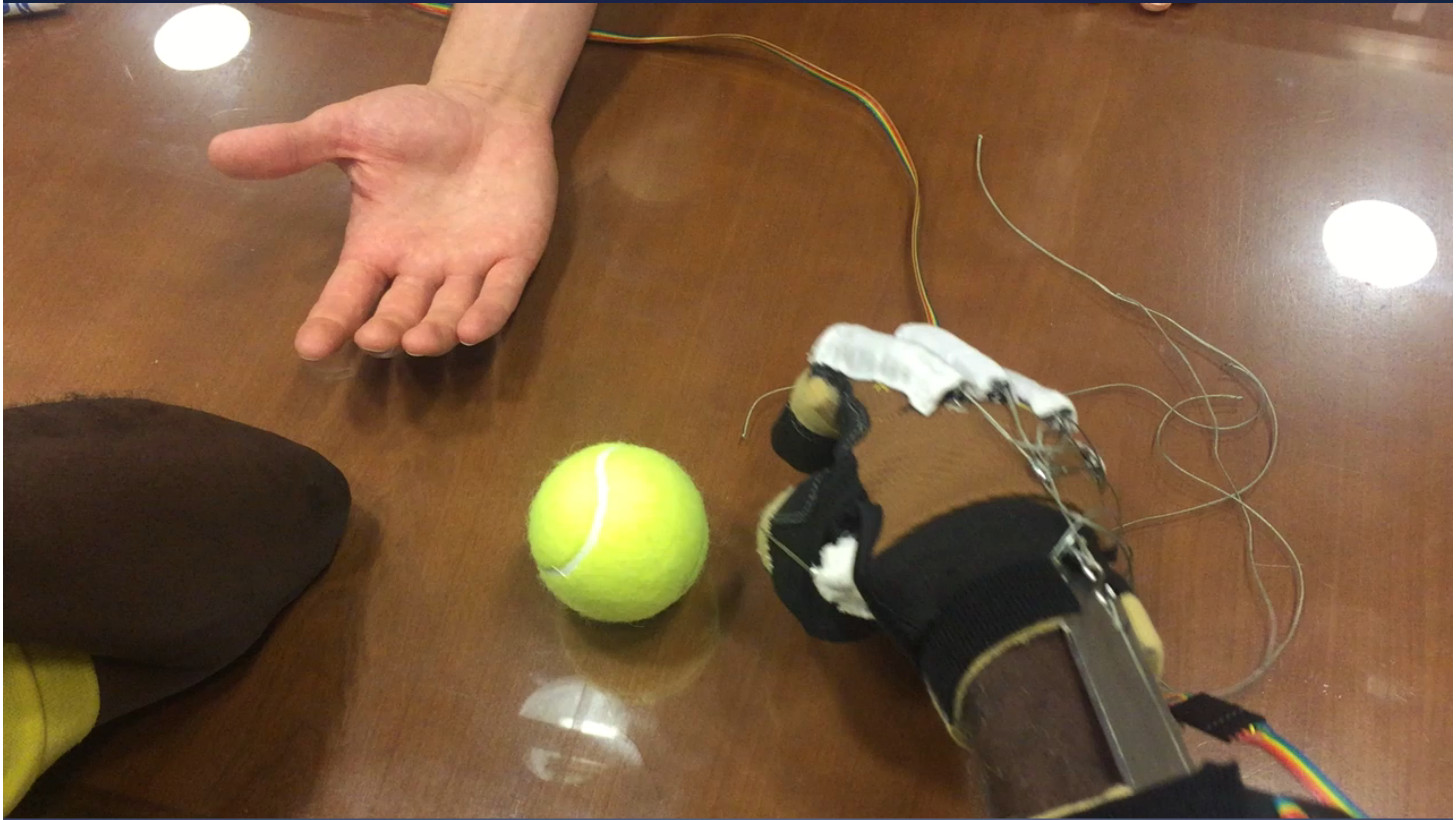
- Advantages:
  - Lightweight from user's perspective
  - Low-inertia
  - Easy to incorporate compliance by inserting springs
  - Can incorporate functional tasks
- Disadvantages
  - Requires external frame – quite large
  - Not practical for home use

Myhand – wearable cable-driven hand orthosis

- PI's: Matei Ciocarlie, PhD (Engineering) and Joel Stein, MD
- Funded by NSF through National Robotics Initiative
- Developing wearable robotic orthosis for use in the home environment for more extensive upper limb exercise/ practice

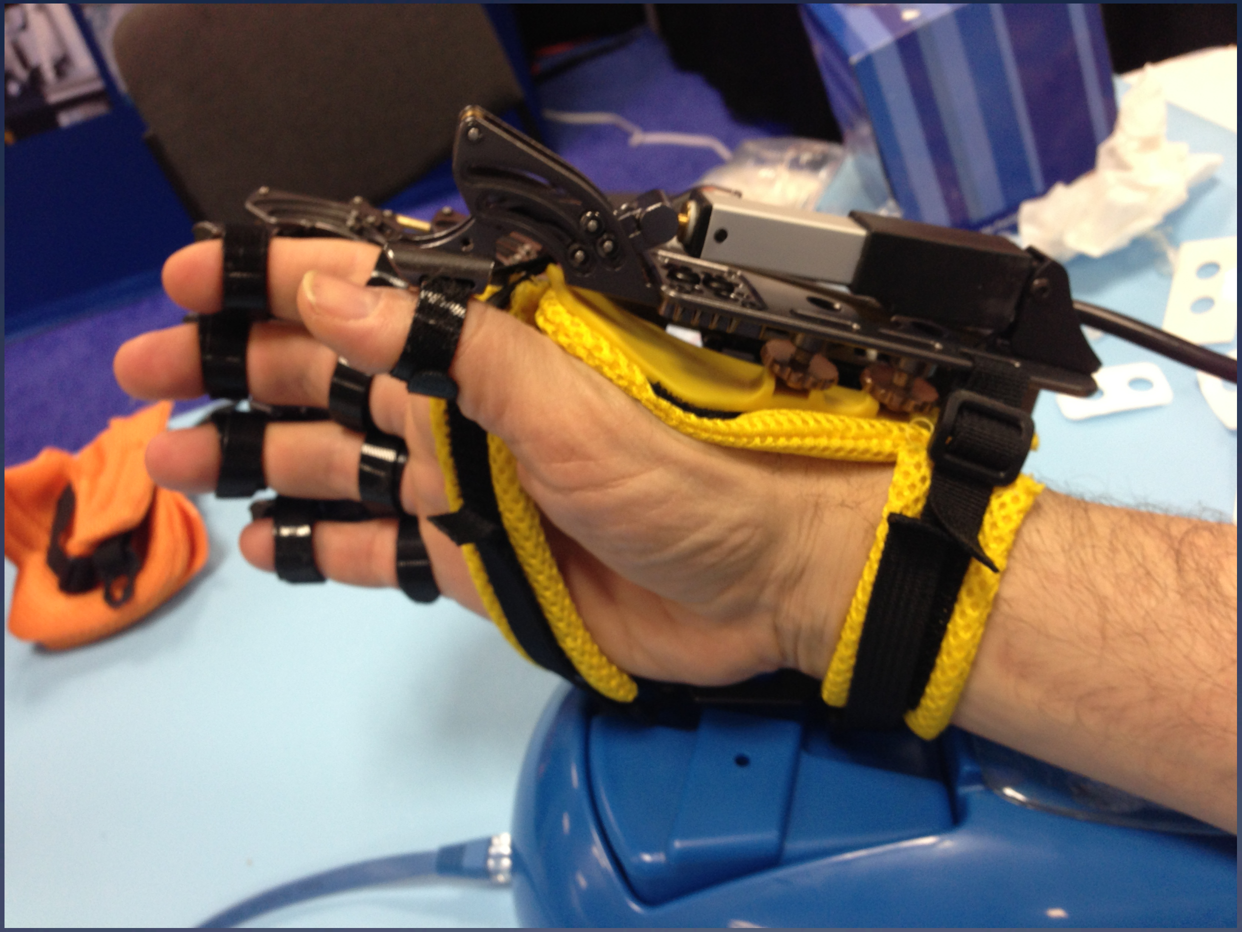


MyHand



C-Alex

Semi-wearable: Hand of Hope



Rehab-Robotics, Hong Kong

Semi-wearble: Bionik InMotion Ankle robot

Video courtesy of Bionik

Wearable Exoskeletal Exercise Robots

Myomo MyoPro

Photo courtesy of Myomo

Soft Robotics

* Fluidic actuators
* Wearable textiles (Exosuit)

From Conor Walsh Lab (Harvard)

Wearable Robots: Limitations

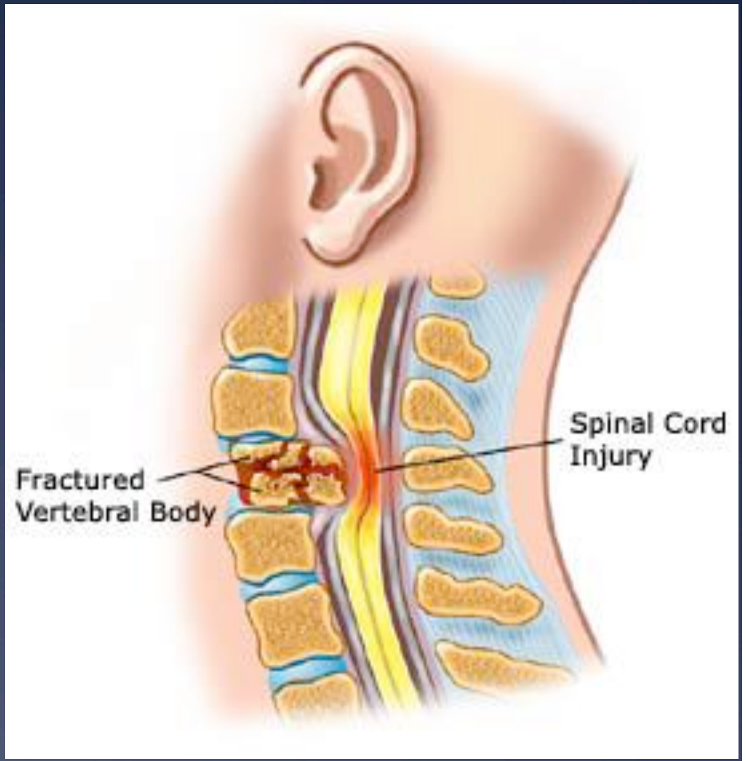
* Limited degrees of freedom
* Functional abilities remain quite limited
* Control systems are crude (mostly EMG)
* Expensive
* Custom design makes therapeutic trials difficult
* Difficult to don and doff
* Spasticity may interfere with use

Summary: Exercise Robotic Design Factors

* End-effector robots constrain movement less than exoskeletal
* Exoskeletal robots allow control of all relevant joints, but at the cost of expense, inertia, complexity, and potentially constraining movement excessively.
* Cable-driven robots may require external frame.
* Soft robotics is a new and developing approach, some actuators may not deliver sufficient force.
* Wearable devices may allow incorporating functional tasks into training easily, and allow home practice to maximize robotic training, but generally carry the limitations of exoskeletal devices.

Wearable Powered Braces

- Target Population: SCI
- Relatively predictable impairments
- Stable impairments over time
- Many young individuals who are highly motivated
- Relatively small population (12,000 annually; 250,000 living with SCI)
- Unclear potential for plasticity



ReWalk (ReWalk Robotics)

Wearable Lower Limb Devices

Ekso ReWalk Indego

Wearable Powered Braces: Barriers

- Cost
- Are these devices “Medically necessary” DME from an insurance company perspective?
- Balance, fall risk
- Complexity
- Durability, reliability
- Battery life
- Difficulty donning/doffing independently
- WC storage, integrating with daily routine for wheelchair users

ADL Assistant Robots

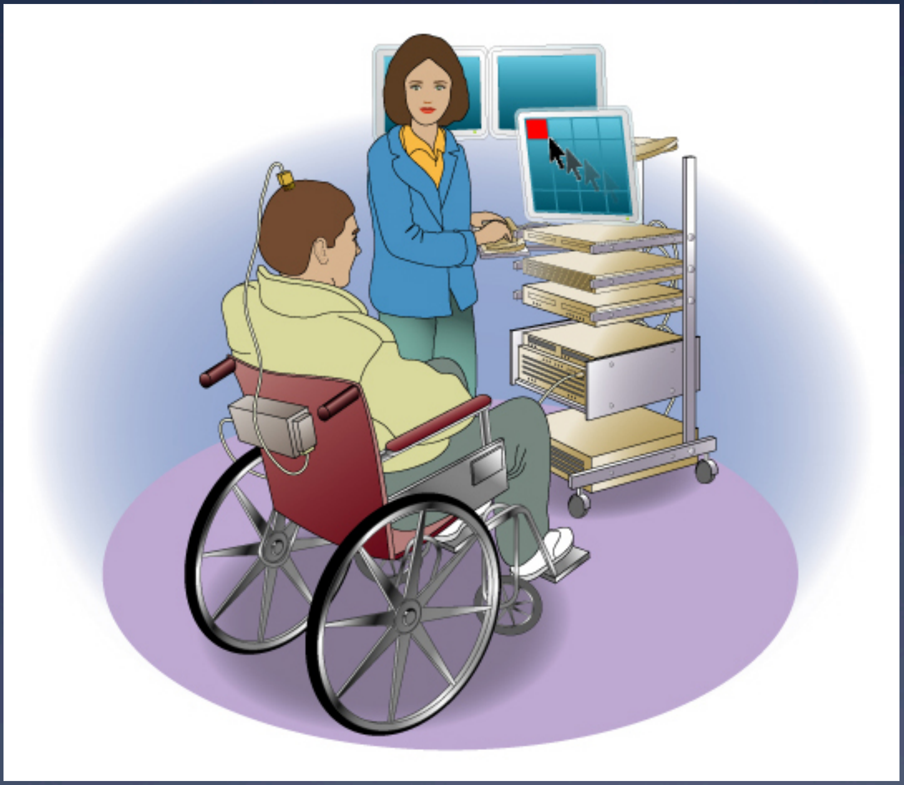
- Wheelchair mounted robotic arms
- May incorporate brain-computer interfaces for neuroprostheses

ADL Assistant Robots

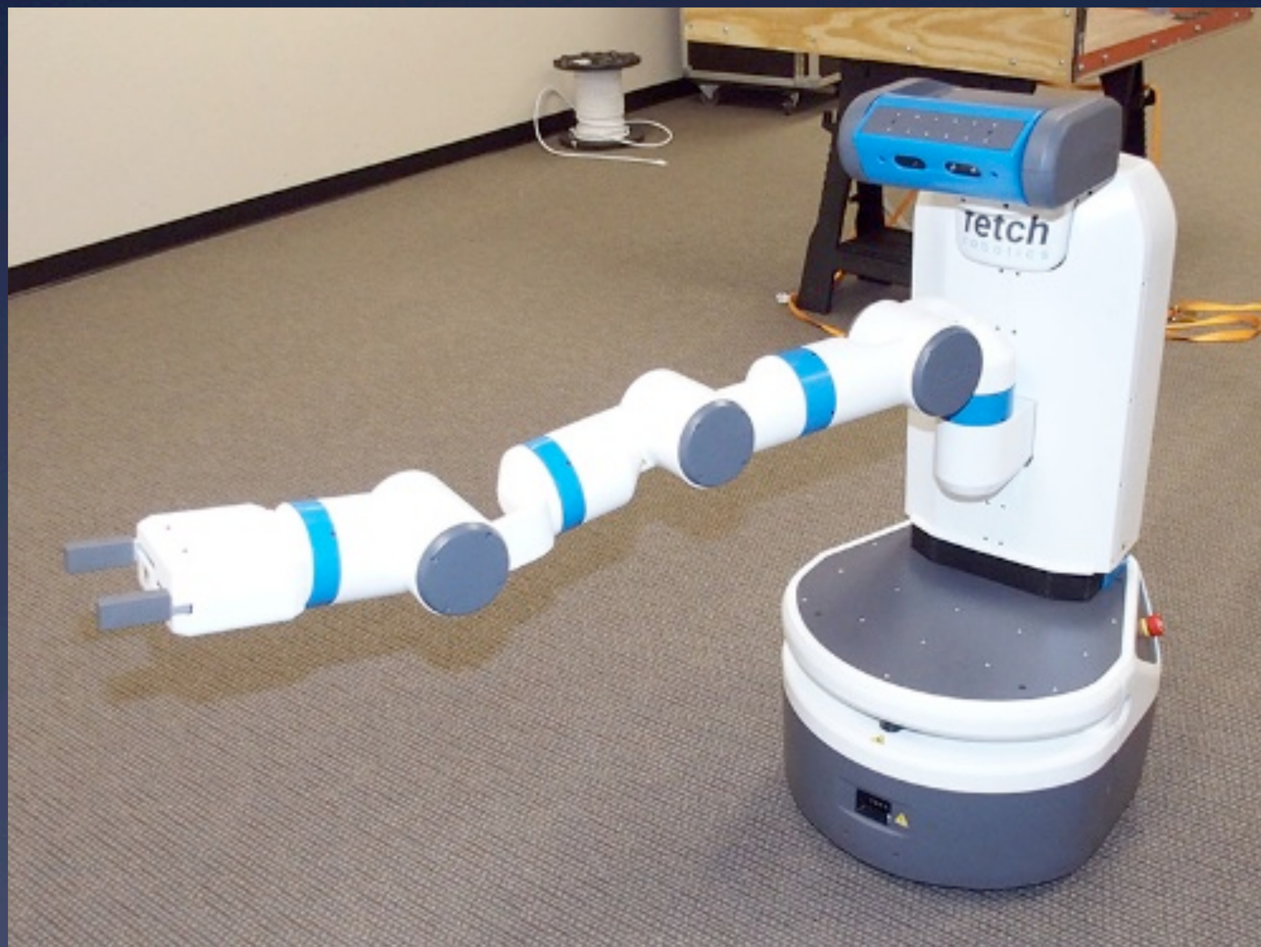
iARM, Exact Dynamics

JACO, Kinova

Brain Computer Interfaces



Fetch and Retrieve Robots



ADL Assistant robots: Barriers

* High cost
* DME insurance limits, “Medical Necessity” definitions
* Limited utility of systems may not reduce need for human caregiver (e.g. to suction a patient’s trachea), assist with toileting
* Control systems remain a weakness, and the use of these devices (e.g. WC mounted robotic arm) demand a lot of attention, cognitive effort, visual-spatial skills, time and effort.
* Neuroprosthetic systems remain in their infancy
* Need robotic engineering to reduce complexity of control tasks

Social/Telepresence Robots

Willow Garage PR2

Telemedicine/
Telepresence

Social/Telepresence Robots

* Limited research thus far
* Need to better define target population and goals
* Most systems not designed for rehabilitation populations

AHA Stroke Rehab Guidelines

* Robotic therapy is reasonable to consider to deliver more intensive practice for individuals with moderate to severe upper limb paresis.(IIa, A)
* Robot-assisted movement training to improve motor function and mobility after stroke in combination with conventional therapy may be considered. (IIb, A)
* Mechanically assisted walking (treadmill, electromechanical gait trainer, robotic device, servo-motor) with body weight support may be considered for patients who are nonambulatory or have low ambulatory ability early after stroke. (IIb, A)

Winstein CJ, Stein J, Arena R, Bates B, Cherney LR, Cramer SC, Deruyter F, Eng JJ, Fisher B, Harvey RL, Lang CE. Guidelines for adult stroke rehabilitation and recovery. Stroke. 2016 Jun 1;47(6):e98-169.

Conclusions

* Robots provide a method for providing well-defined, reproducible therapeutic exercise in a potentially labor-saving fashion.
* Advantages of robots for delivery of exercise therapy compared with conventional therapy remain promising but still unproven.
* Robots can be a tool to determine the optimal exercise algorithms.
* Wearable powered braces are a promising approach for patients with paraplegia, but not yet ready for widespread home use, and unclear utility in stroke.
* Better control methods and/or smarter devices are needed for widespread adoption of ADL robots

For More Information:

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