Rethinking Rehabilitation:

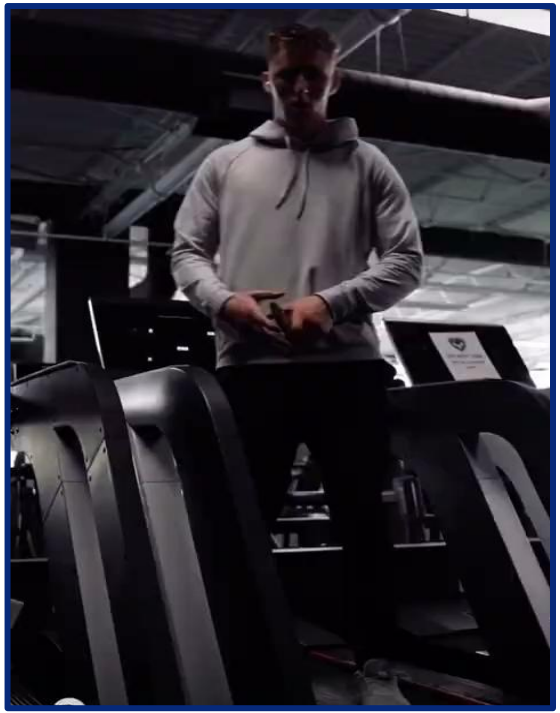
Improving Function & Inspiring Hope

Kristin Nuckols OTD, MOT, OTR/L
Cofounder & Chief Clinical Officer

800,000 Americans per year*

Stroke doesn't discriminate

https://www.susanreed.com



https://www.instagram.com/jacksmi1ey

*ASA/AHA Stroke Update 2023

800,000 Americans per year*

Susan

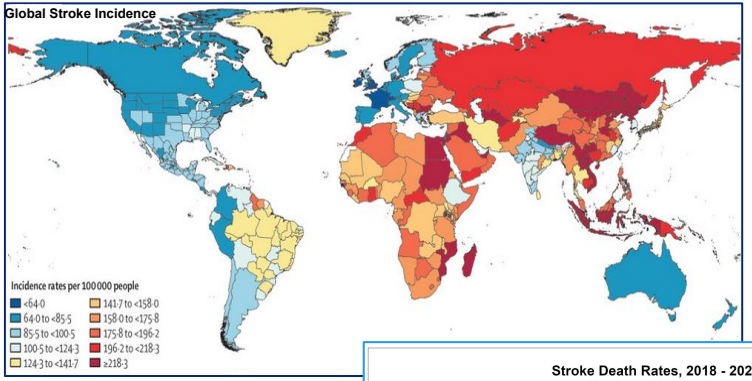
https://www.susanreed.com

Jack

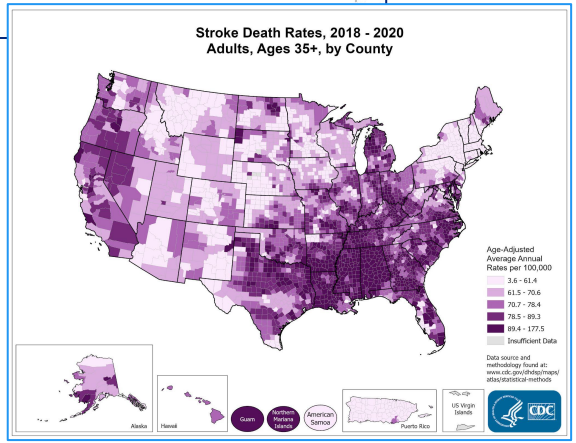
https://www.instagram.com/jacksmiley

A global problem

- Leading cause of disability worldwide
- Second leading cause of death
- Risk of stroke +50% in past 20 years
- 1 : 4 people is predicted to have a stroke in their lifetime



https://www.thelancet.com/journals/laneur/article/PIIS1474-4422(21)00252-0/fulltext



Howard & Howard. Stroke. 2020;51:742-750. DOI: 10.1161/STROKEAHA.119.024155.

Good News → more people are surviving strokes

Not as Good News → more people are living with increased rates of disability (DALY)

Imago REHAB

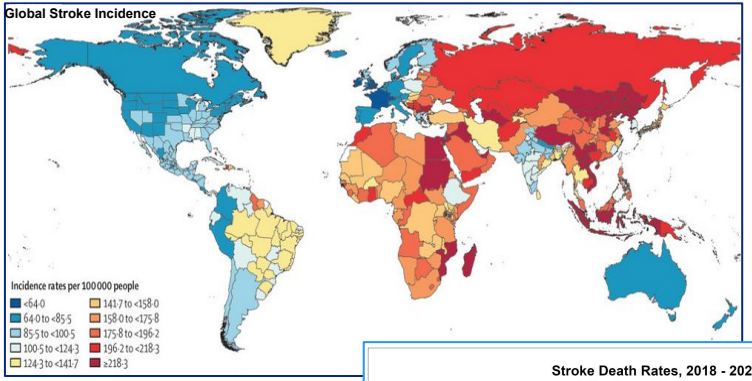
A global problem

Leading cause of disability worldwide

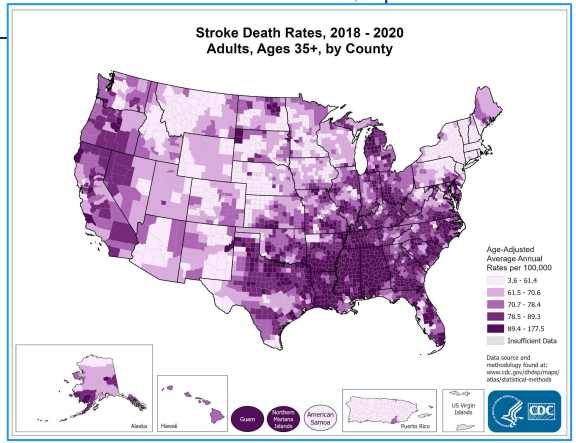
Second leading cause of death

Risk of stroke +50% in past 20 years

1 : 4 people is predicted to have a stroke in their lifetime



https://www.thelancet.com/journals/laneur/article/PIIS1474-4422(21)00252-0/fulltext

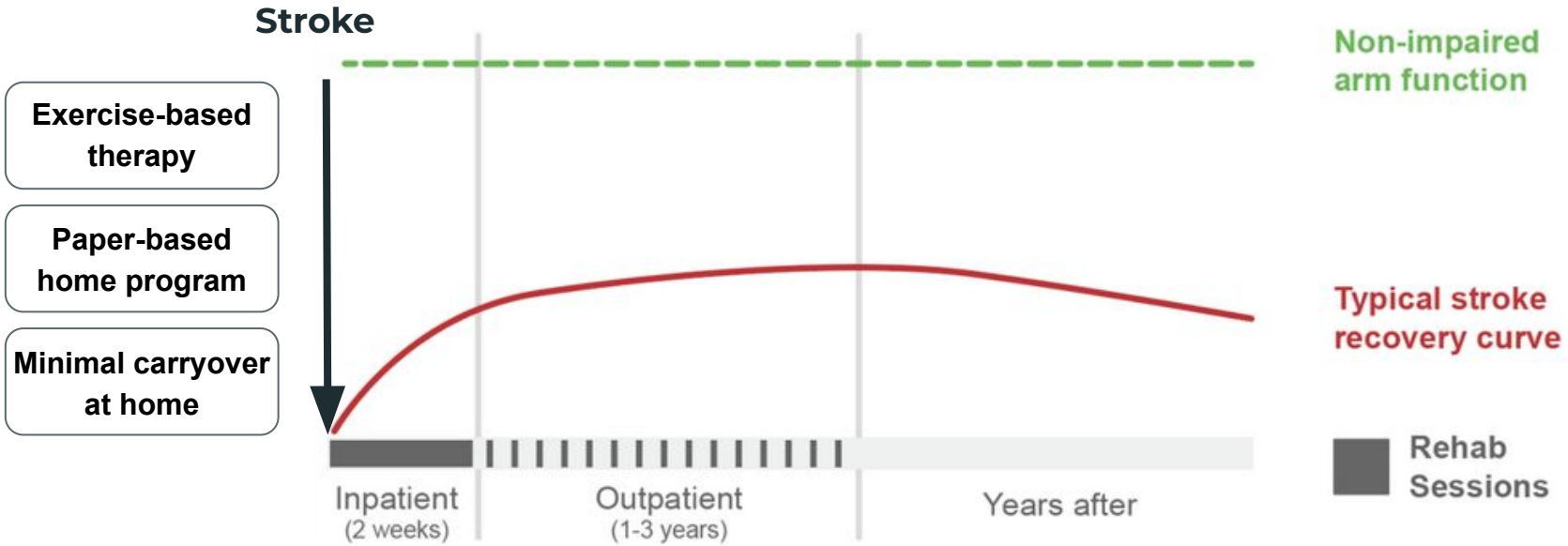


Howard & Howard. Stroke. 2020;51:742-750. DOI: 10.1161/STROKEAHA.119.024155.

- Good News → more people are surviving strokes
- Not as Good News → more people are living with increased rates of disability (DALY)

Imago REHAB

Traditional Stroke Recovery



https://www.ahajournals.org/doi/10.1161/STROKEAHA.122.041098?utm_source=miragenews&utm_medium=miragenews&utm_campaign=news

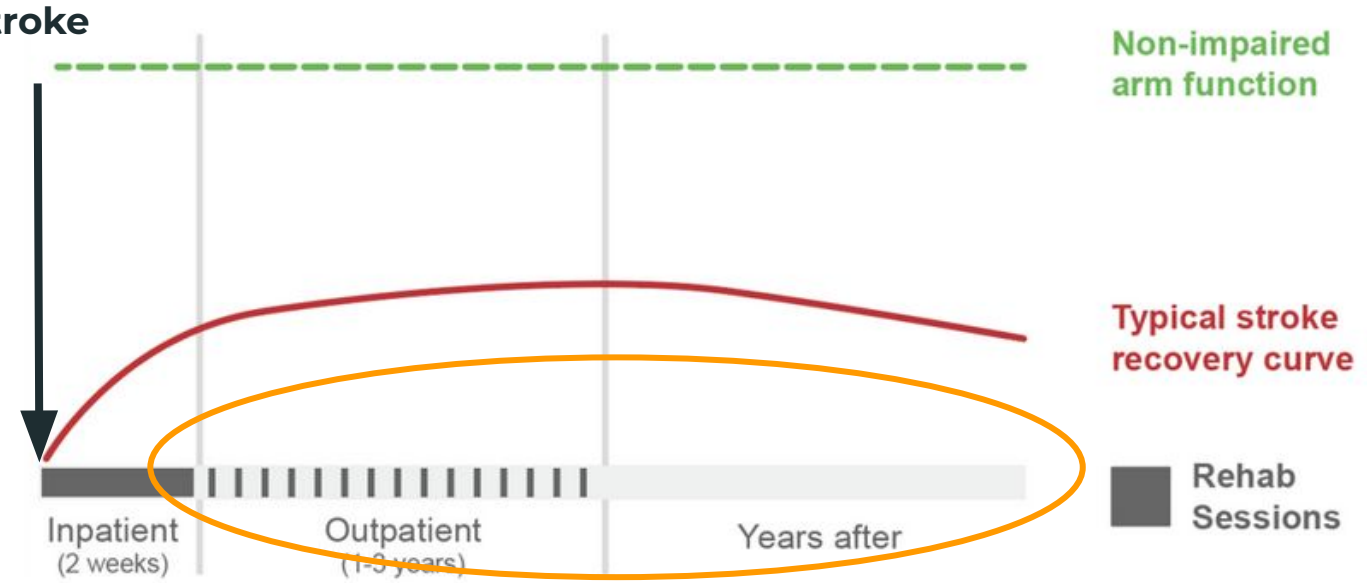
Imago REHAB

Traditional Stroke Recovery

Within 30 days:
⅓ ➔ **received 0 rehab services**

Within 90 days, clients with stroke received **6-8 sessions** of combined therapy

After 90 days, they received on avg **0- 1.5 sessions**



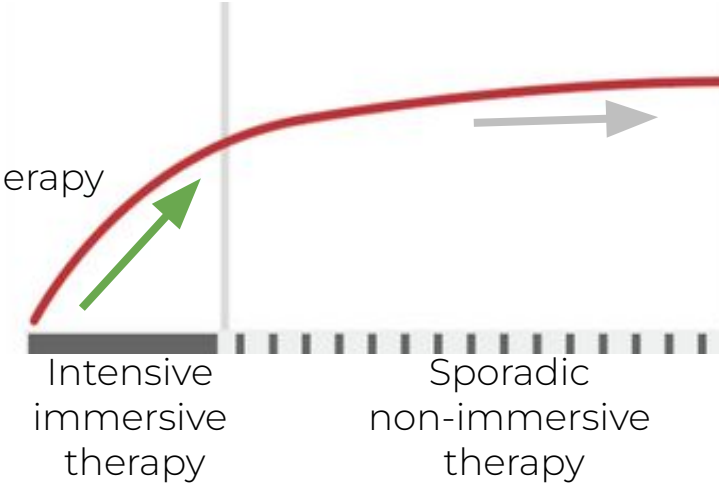
https://www.ahajournals.org/doi/10.1161/STROKEAHA.122.041098

Imago REHAB

Traditional Stroke Recovery

Why such little therapy?

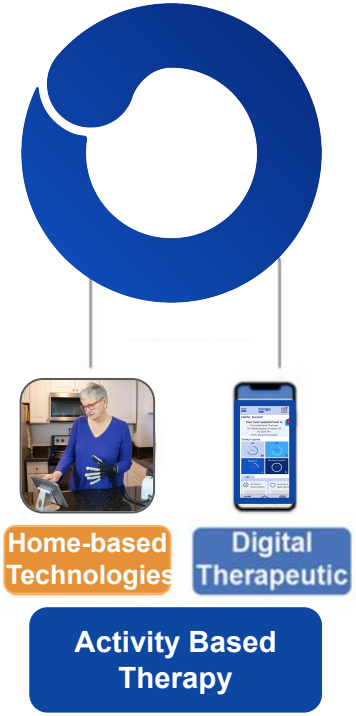
- Accessibility of high quality rehabilitation services
  - Transportation
  - Availability
  - Insurance benefits/cost of therapy
- The dreaded plateau…
  - Is it any surprise?

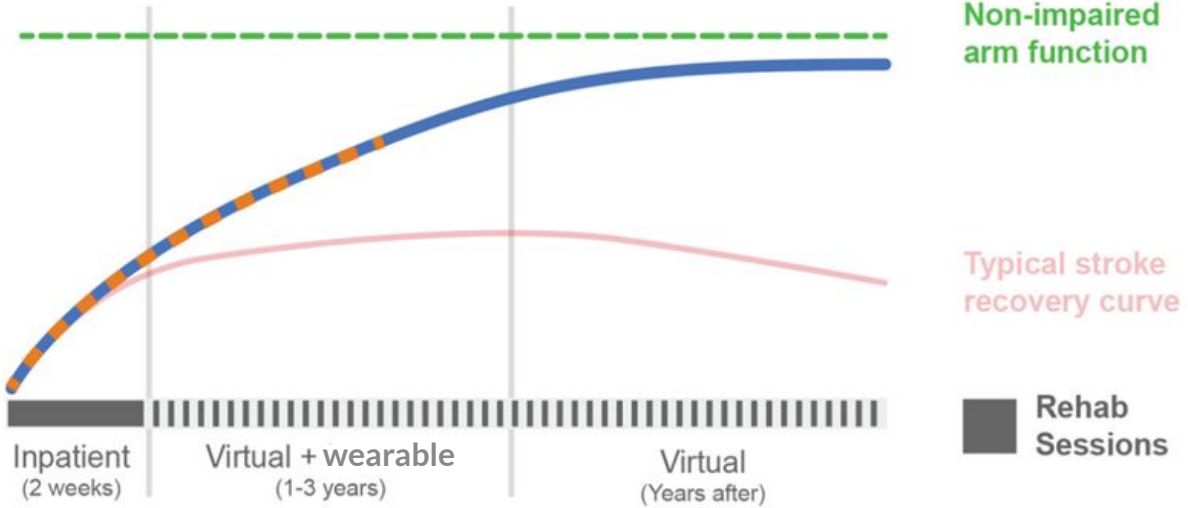


Are you ready for a better vision for stroke recovery?

Imago
REHAB

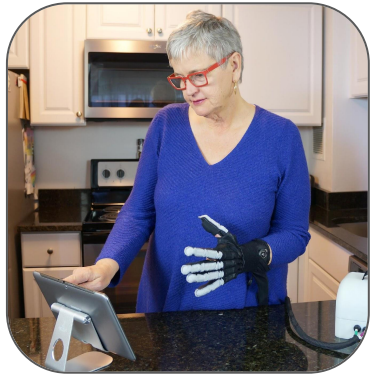
A better vision for stroke and brain injury rehabilitation





Imago REHAB

A better vision for stroke and brain injury rehabilitation



Home-based Wearable Technologies

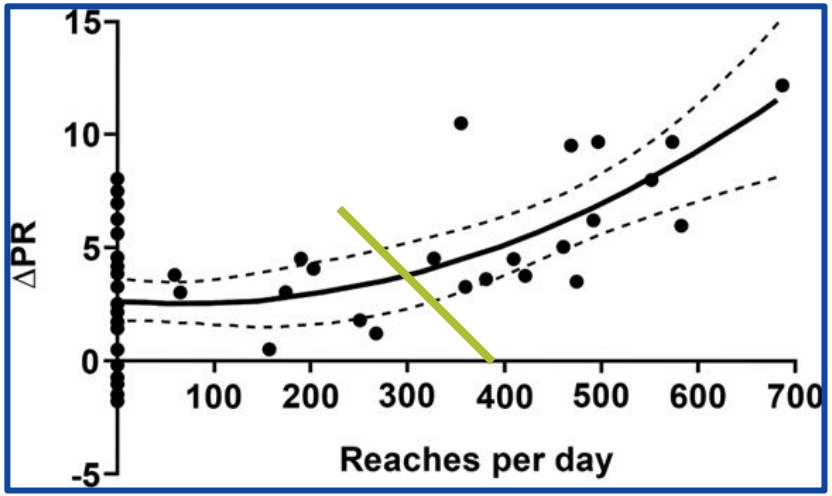
Digital Therapeutics

Activity Based Therapy

What is needed to change the brain post-stroke?

32 reps per session vs 300 reps per session

Category or subcategory	% (no.) of sessions observed in*	Repetitions/ session
Upper extremity		
Active exercise	36 (13)	38.8
Passive exercise	47 (17)	33.9
Purposeful	44 (16)	12.0
Sensory	17 (6)	2.5



Lang *et al.* 2007

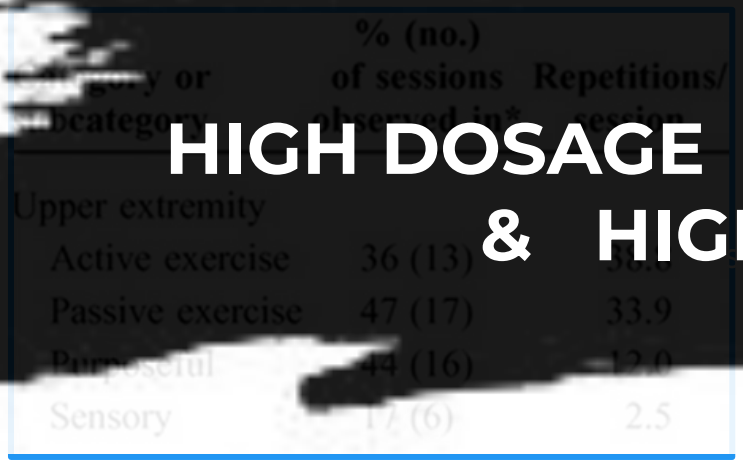
Jeffers *et al.* 2018

Imago REHAB

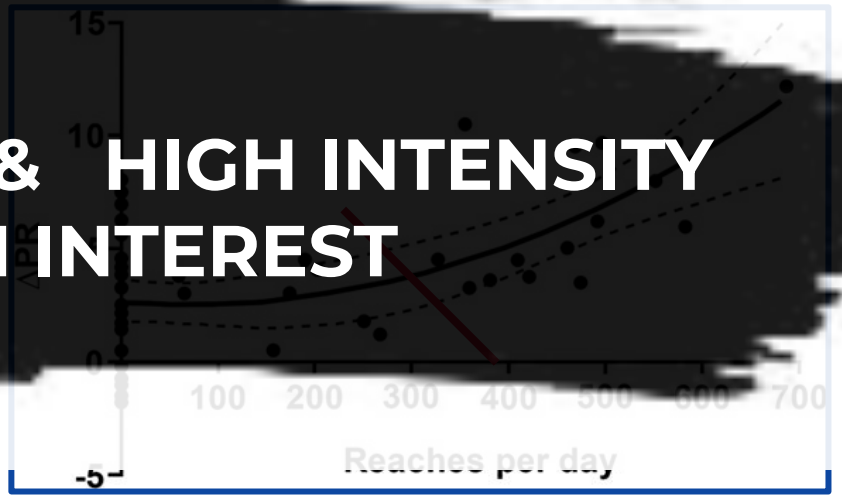
What is needed to change the brain post-stroke?

32 reps per session vs 300 reps per session

HIGH DOSAGE & HIGH INTENSITY & HIGH INTEREST



	% (no.) of sessions observed in*	Repetitions/ session
Upper extremity		
Active exercise	36 (13)	38.2
Passive exercise	47 (17)	33.9
Purposeful	44 (16)	12.0
Sensory	17 (6)	2.5



Lang *et al.* 2007

Jeffers *et al.* 2018

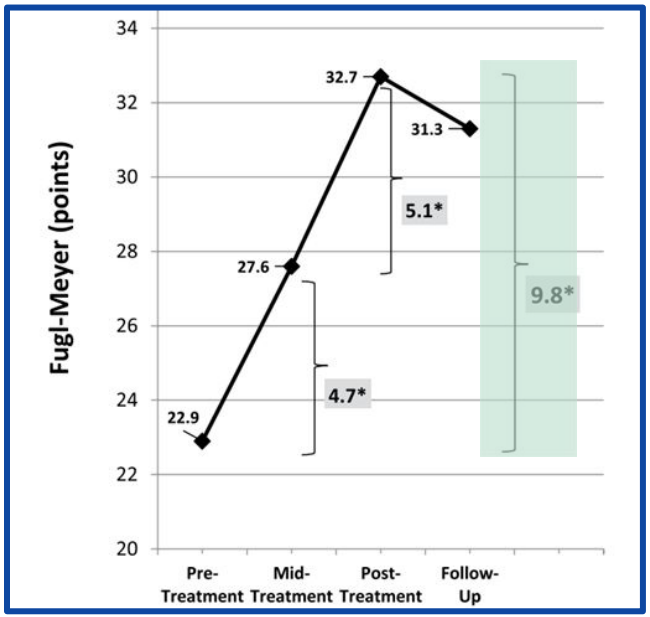
Imago REHAB

“Best Case” Clinical Therapy

Chronic stroke

Moderate or more spasticity

Technology-based care with functional electrical stimulation and arm/hand robotics



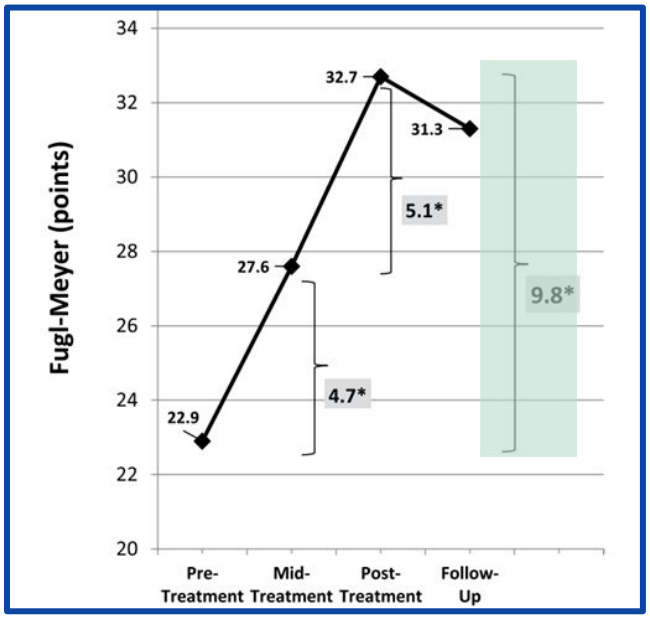
Daly *et al.* NNR 2019

“Best Case” Clinical Therapy

Chronic stroke

Moderate or more spasticity

Excellent change on assessments!



Daly *et al.* NNR 2019

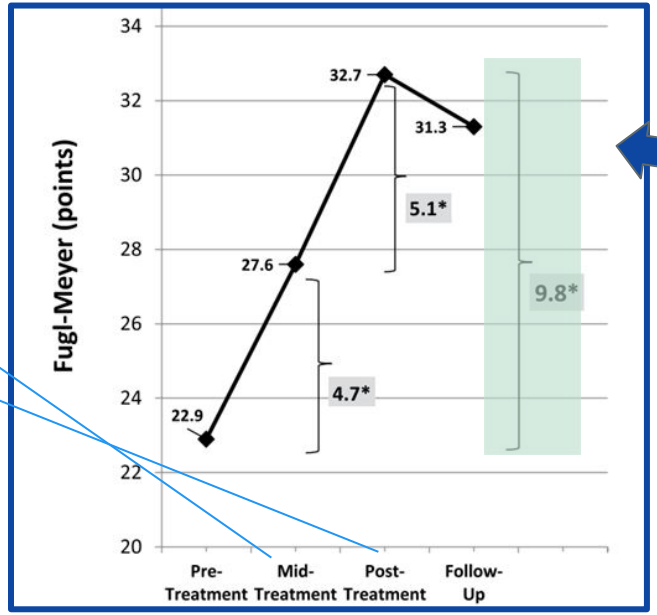
Imago REHAB

“Best Case” Clinical Therapy

Mid-Treatment: **150 hours** of therapy (6 wks)

Post-Treatment: **300 hours** of therapy (12 wks)

5 hours of therapy per day
5 days a week



Excellent change in FMA-UE!

Daly *et al.* NNR 2019

Imago REHAB

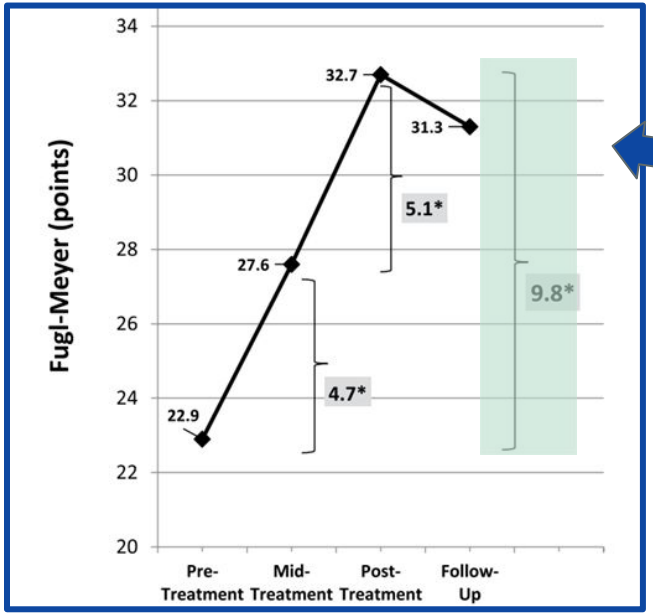
“Best Case” Clinical Therapy

5 hours of therapy per day

5 days a week

Over 6 weeks =

45,000 reps?



Excellent change in FMA-UE!

Daly *et al.* NNR 2019

“Best Case” Clinical Therapy…in reality

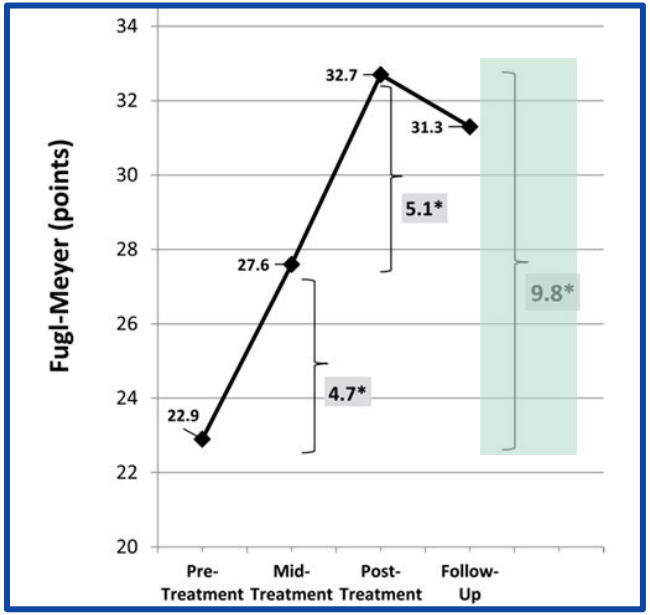
60 car rides to and from hospital facility

Care partner time and effort

6 weeks spent out of work, home, family routines to do therapy

No known carryover to activities of daily living

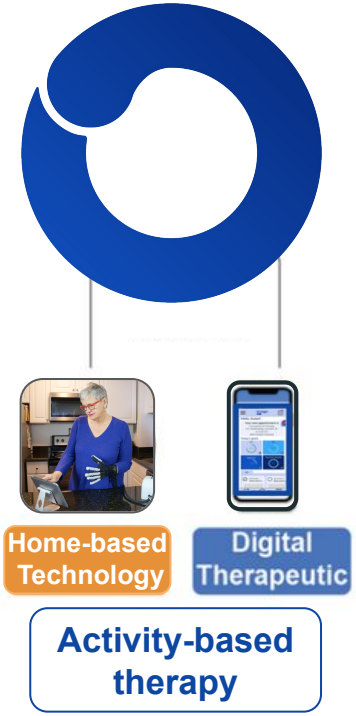
$5,000 cost of therapy model (per authors)

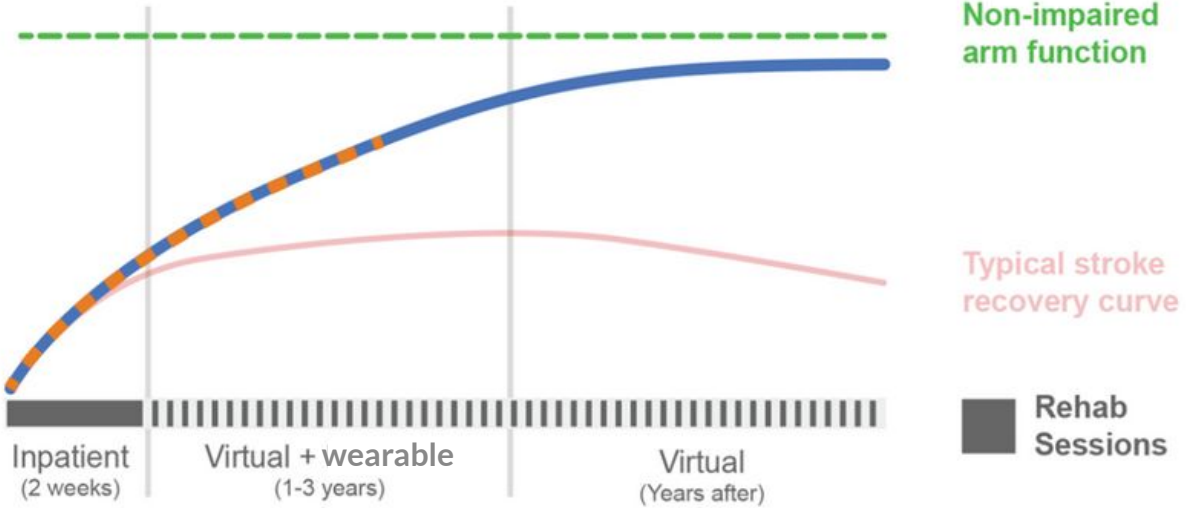


Daly *et al.* NNR 2019

Imago REHAB

A better vision for stroke and brain injury rehabilitation





Imago REHAB

Rehabilitation of the future

People need MORE rehab.

People need BETTER rehab.

Rehab needs to happen at HOME.

Imago REHAB

“Best Case” Clinical Therapy = Imago Rehab’s reality

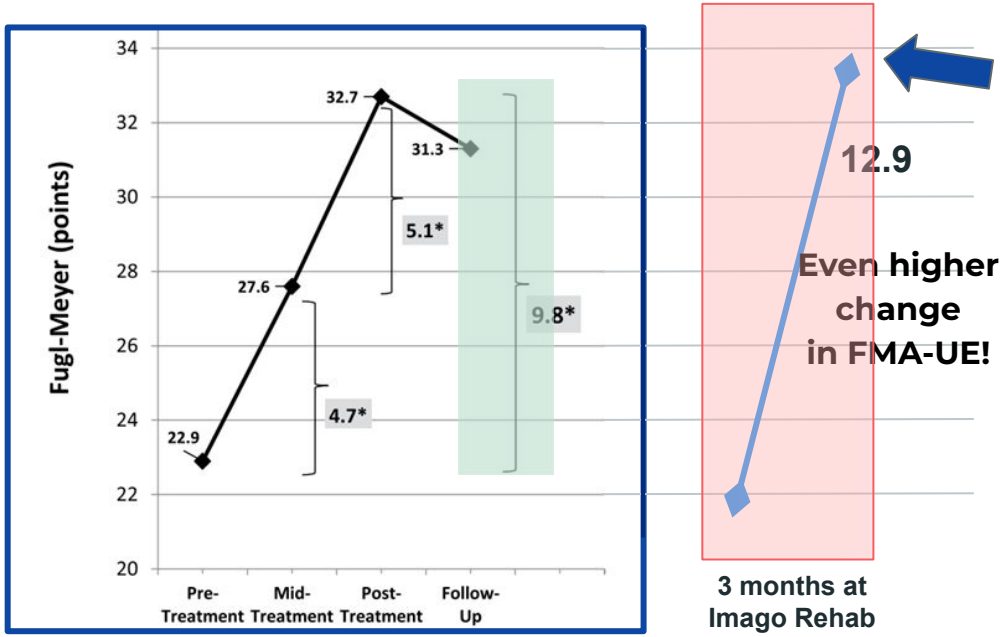
Therapy from home

Minimal care partner time and effort

Therapy embedded into your work, home, and family routines

Significant carryover to activities of daily living

2x week therapy at cost of your insurance plan therapy provision



Daly *et al.* NNR 2019

Introducing a *different* kind of robot

Harvard University: Bioinspired Robotics: Smarter, Softer, Safer

Imago REHAB

Wearable Technology for Stroke Rehabilitation

https://biodesign.seas.harvard.edu/

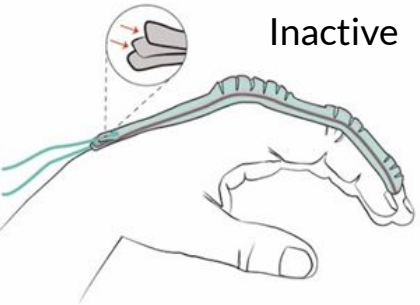
Harvard John A. Paulson School of Engineering and Applied Sciences

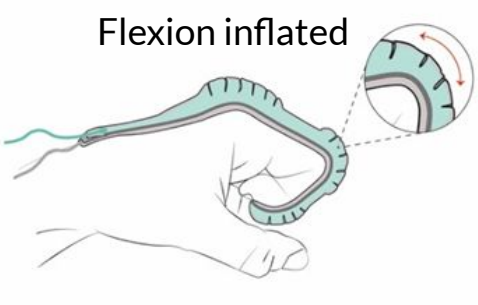
Imago REHAB

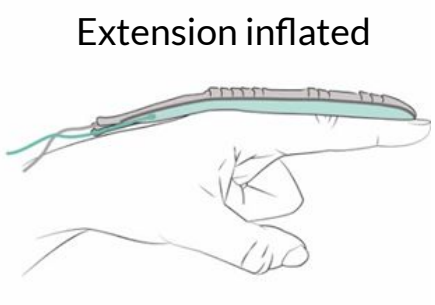
Pneumatic Actuation of the Hand

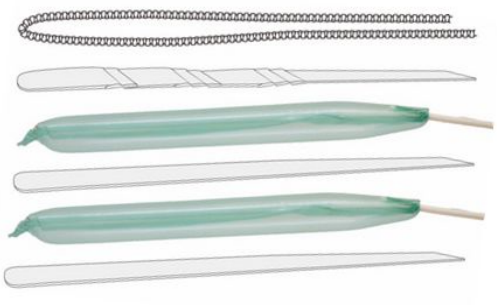
Inflatable chambers sandwiched with flexible and inflexible fabrics

- Unobtrusive when “off”
- Helpful, safe, comfortable when “on”
- Mimics the biological structure



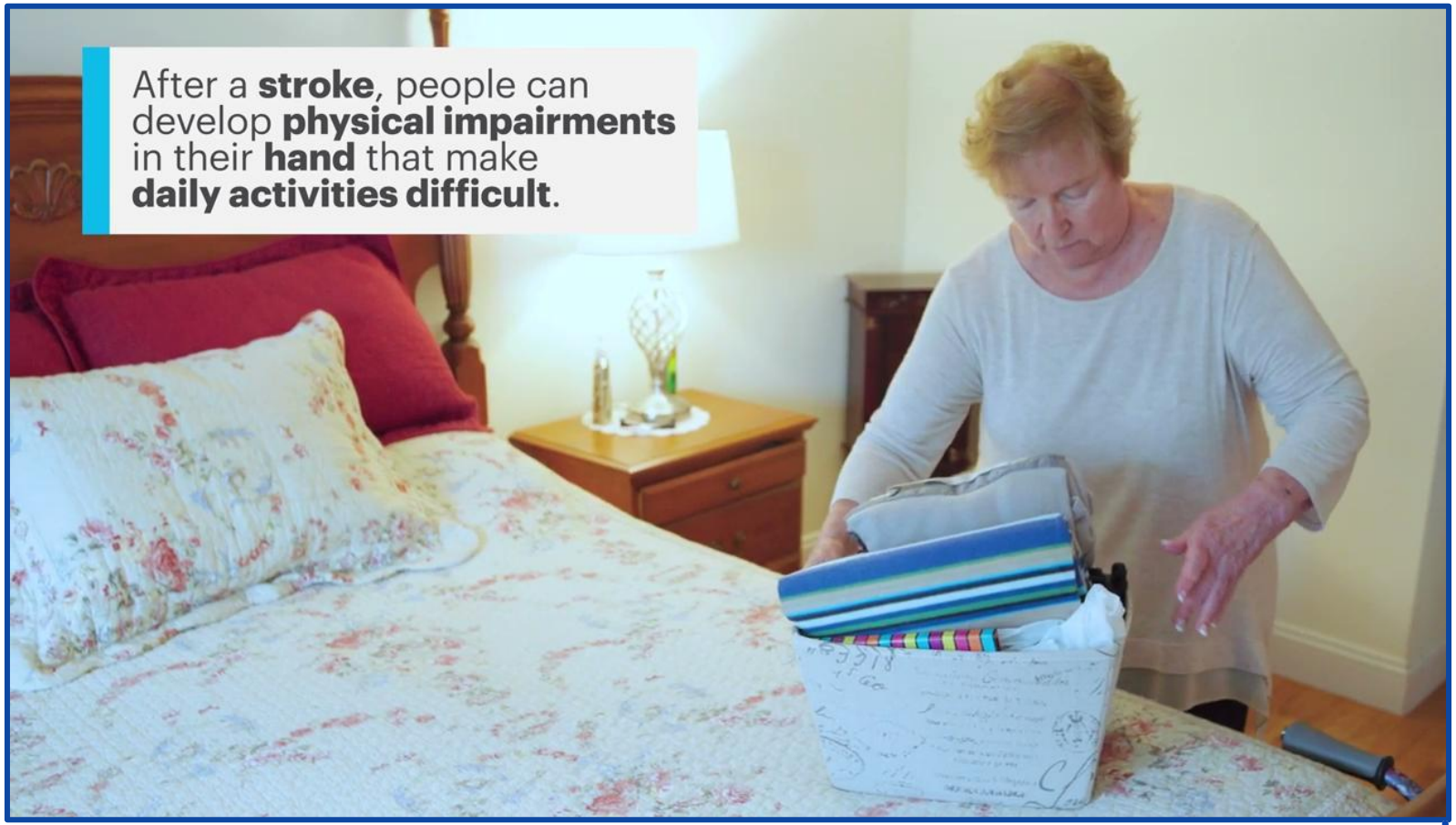






Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

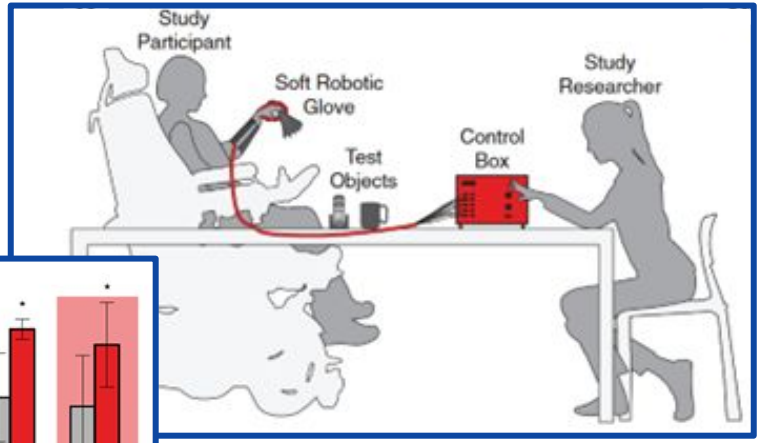


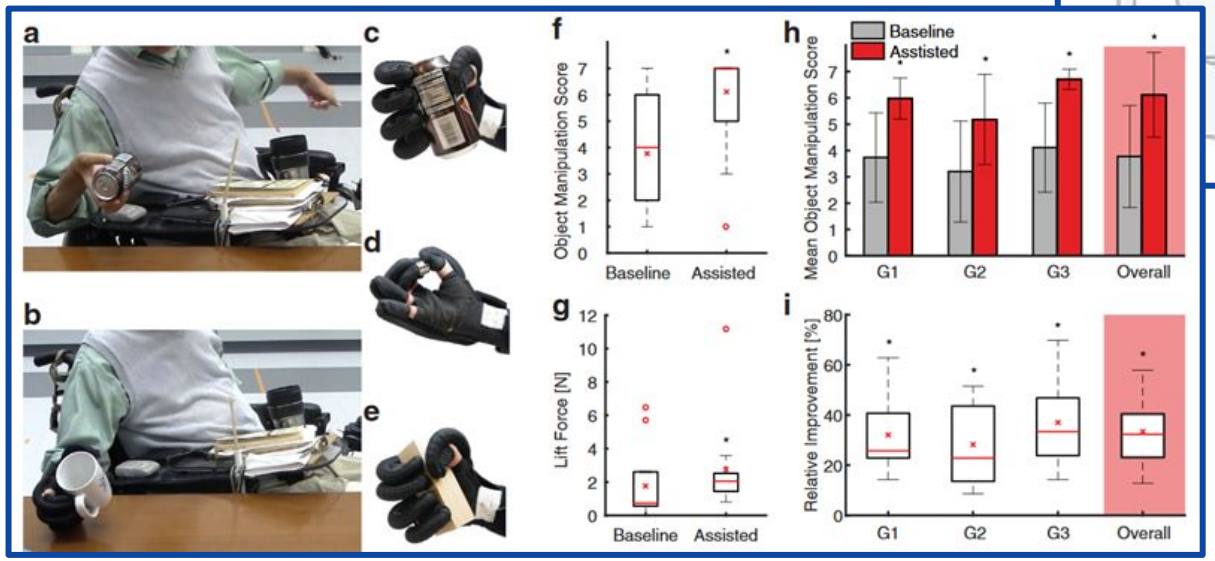
Video credit: Wyss Institute, John A Paulson School of Engineering and Applied Sciences

Imago REHAB

Glove Research Phase 1

Researcher controlled the glove for either grasp or pinch assistance





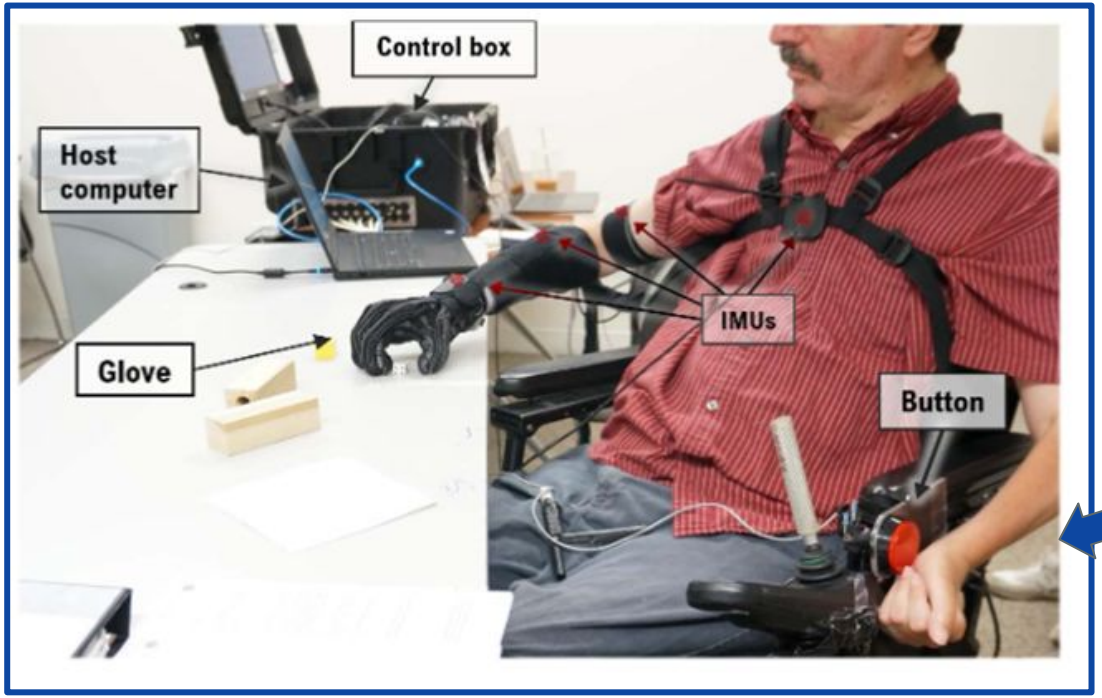
30% improvement
9 individuals with
C4-7 SCI

Cappello *et al.* (2018)

Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

Glove Research Phase 2



Grasp strength ↑ 2 lbs

Significant increase in ROM

50% ↑ managing objects

Glove controlled by user

Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

Glove Research Phase 3

Introduction

- **Stroke** is a leading global **healthcare burden** (Benjamin, Circ, 2018)
- 80% of survivors have **lasting physical impairments** (Chen & Winstein, Jr Neuro PT, 2009)
- Limitations in access to rehabilitation (O'Brien, Phy Ther, 2013), have created a need for **at-home therapy devices**
- Wearable devices such as **soft robotics** are poised to fill this gap in treatment

Methods

Population: Four participants with chronic stroke

Study design: Pre-and-post intervention

Outcomes:
- Modified Ashworth Scale (**MAS**)
- Range of Motion (**ROM**)
- **Grip Strength** via dynamometer
- **Grip Termination** via finger flexor EMG

Intervention:
- Baseline, Training Visits 1-6, Post Intervention
- Training included:

1) Cyclic stretching of flexors x 120
2) Active-assisted exercise of flexors/extensors x 12
3) Repetitive **task-oriented training** x 60

Results

Modified Ashworth Scale

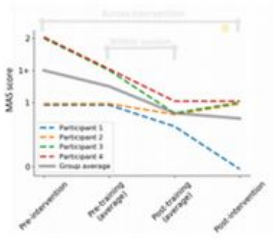


Figure 1: Upper extremity MAS score progression throughout the study

MAS scores **decreased by 1 point** across the study

Range of Motion

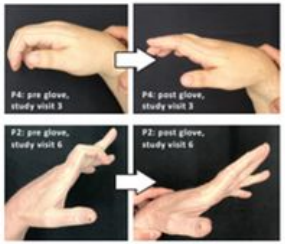


Figure 2: Change in maximum voluntary extension within one training visit

Maximum MCP extension angle **increased by 18.5°** within session

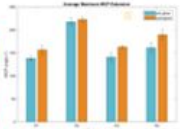


Figure 3: Change in maximum degree of MCP extension pre- and post-glove, averaged through 6 training visits

Grip Termination

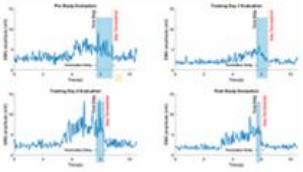


Figure 5: Sample EMG data from Participant 3 showing grip termination (flexor muscle relaxation) after hearing an auditory tone

Decreased time to terminate grip: for further exploration

Grip Strength

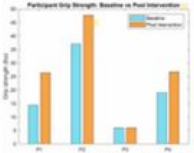


Figure 4: Grip strength change from Baseline to Post Intervention visits

Grip strength **increased by 7.4 lbs (33N)**

Discussion

- **Reduction in hyperexcitability** of finger muscles both within session and pre-to-post
- **Increase in finger extension ROM** within session
- **Increase in grip strength** in 75% of subjects within session and pre-to-post
- **Grip termination** trends were inconclusive between subjects but worth further exploration

Future Work

- **Intuitive control strategies** using sensors
- **Fully portable system**
- Randomized controlled trial

Our vision for **individualized home-based therapy** with a portable, intuitive **wearable system**

Acknowledgements

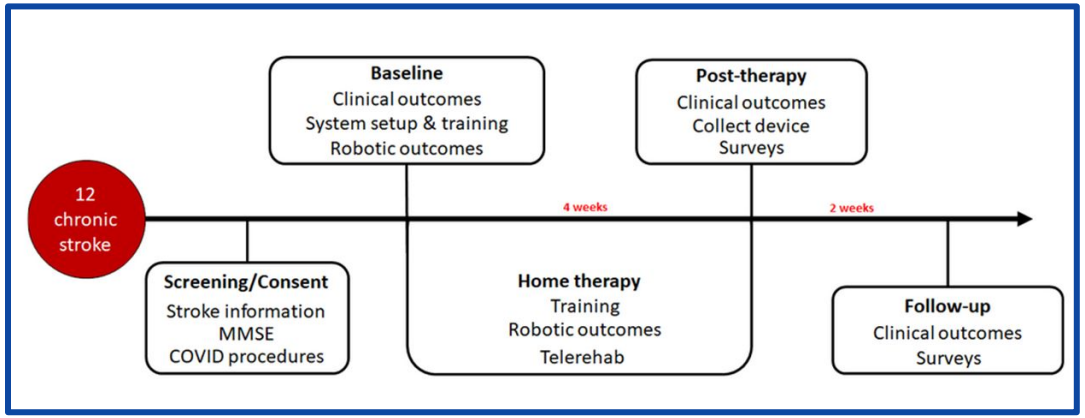
Funding was provided by the Wyss Institute for Biologically Inspired Engineering at Harvard University. This study was approved by the Harvard Medical School IRB Protocol BIR-CS-0006. We want to thank Tim Walsh, the Clinical Research team, and our participants for their time and effort.

Nuckols, *et al.* 2019

School of Engineering and Applied Sciences

Imago REHAB

Glove Research Phase 4



4-week intervention in the home

Telerehab + Home Program

Positive changes in hand/arm function!

Proietti, Nuckols, *et al (2024)*

Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

Pneumatic Actuation of the Arm

Inflatable chambers sandwiched with flexible and inflexible fabrics

Inflatable soft wearable robot for reducing therapist fatigue during upper extremity rehabilitation in severe stroke

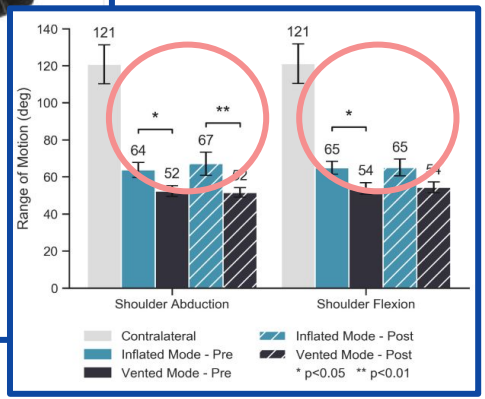
O'Neill C.*, Proietti T.*, Nuckols K., Clarke M., Hohimer C., Cloutier A., Lin D., Walsh C.

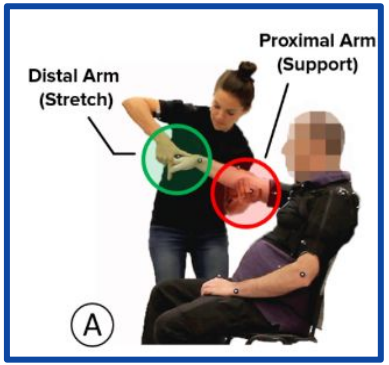
Harvard John A. Paulson School of Engineering and Applied Sciences
Wyss Institute
Harvard Medical School
Massachusetts General Hospital

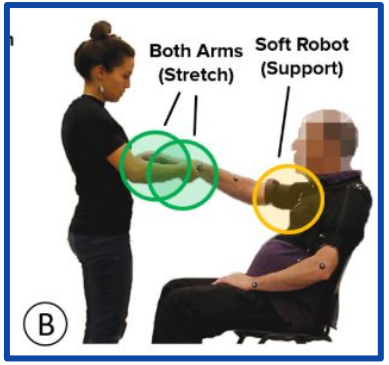
* Indicates equal contributions.

Harvard John A. Paulson School of Engineering and Applied Sciences
Imago Rehab

Stroke Upper Limb Research Phase 1







Assisting clients with severe impairments with and without robotic assistance

O'Neill, Proietti, Nuckols *et al* (2020)

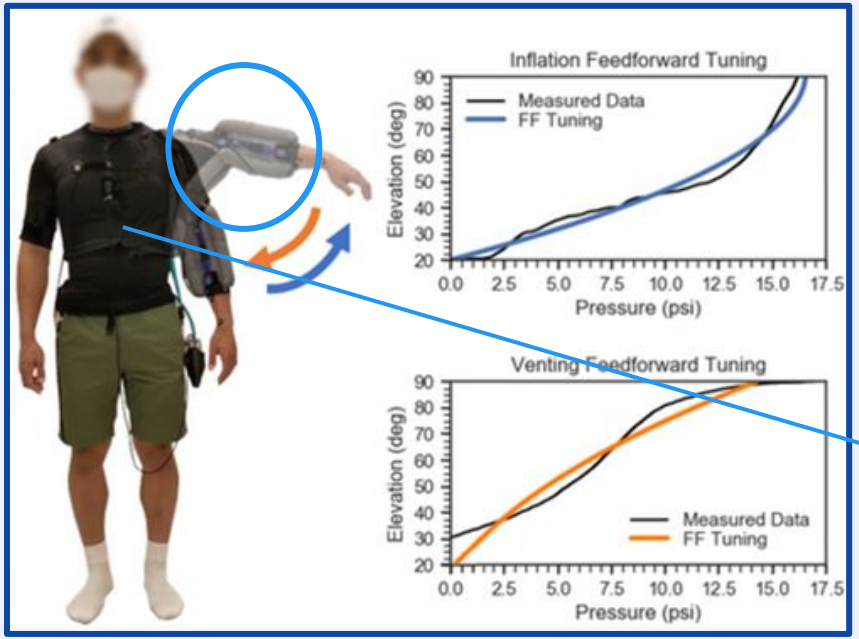
Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

Stroke Shoulder Assist Research Phase 2

HARVARD
John A. Paulson
School of Engineering
and Applied Sciences

Added to the robotic assistance capabilities with sensing and elbow actuation



Proietti, O'Neill, Hohimer, Nuckols *et al* (2020)

Stroke Upper Limb Research Phase 2

Increased arm Torque 60%!

Reduce trunk Compensation

Portable!!!

Proietti, Nuckols et al, 2022

Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

Stroke Shoulder Assist Research Phase 3

Autonomy →

National Science Foundation

Harvard John A. Paulson School of Engineering and Applied Sciences

Imago REHAB

“Discoveries can’t change the world if they never leave the lab”

55 startups
“Lumineers”

1700+ jobs
created by startups

2.2B startup
venture funding

4, 232 patents filed
1,314 issued

2,883 publications

https://issuu.com/wyssinstitute/docs/wyss_institute_impact_report_2023

Imago REHAB

“Discoveries can’t change the world if they never leave the lab”

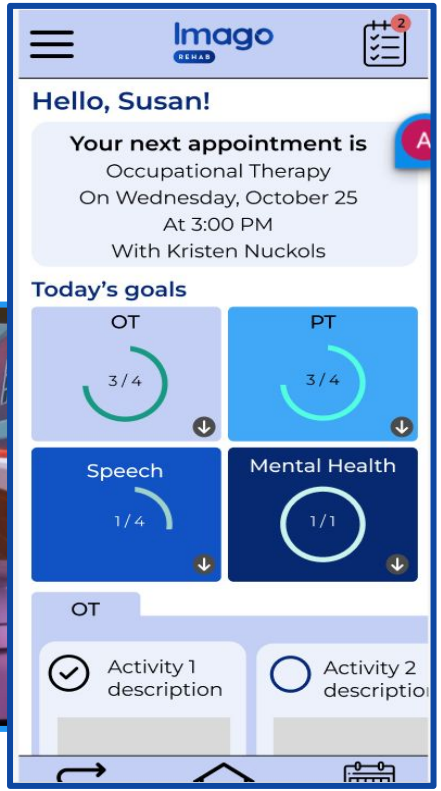
- Launched in 2021 in MA
- Expanded into 5 more states for virtual OT (including VA!)
- Expanded to include Speech and PT
- Covered by Medicare and commercial payers
- Piloting home-based technology use

Pre-FDA Currently studied under Investigational Device Use IRB

Imago REHAB

Tech Development, Cont...

- Digital home program
- Virtual support and engagement
- Gamified therapy
  - RXGames beta pilot*
  - Virtual gaming + tele-rehab as effective as in-clinic CIMT therapy



*https://www.thelancet.com/journals/eclinm/article/PIIS2589-5370(21)00520-4/fulltext

Imago REHAB

Remember Susan & Jack?

Before working with Imago Rehab

https://www.instagram.com/jacksmiley

Imago REHAB

Rethinking Rehabilitation

People need MORE rehab.

People need BETTER rehab.

Rehab needs to happen at HOME.

Imago Rehab is committed to making this vision a reality!

www.imagorehab.com

Imago REHAB

Thank you for your attention!

kristin@imagorehab.com
Phone: 1-888-855-2674
Fax: 617-250-8243

Imago REHAB

References

Cappello, L., Meyer, J.T., Galloway, K.C. *et al.* Assisting hand function after spinal cord injury with a fabric-based soft robotic glove. *J NeuroEngineering Rehabil* 15, 59 (2018). https://doi.org/10.1186/s12984-018-0391-x

Correia, C., Nuckols, K., Wagner, D., Zhou, Y., Clarke, M., Orzel, D., Solinsky, R., Paganoni, S., & Walsh, C. IEEE Transactions On Neural Systems and Rehabilitation Engineering. 28(6). (2020)

Daly, J. J., McCabe, J. P., Holcomb, J., Monkiewicz, M., Gansen, J., & Pundik, S. (2019). Long-Dose Intensive Therapy Is Necessary for Strong, Clinically Significant, Upper Limb Functional Gains and Retained Gains in Severe/Moderate Chronic Stroke. *Neurorehabilitation and neural repair*, *33*(7), 523–537. https://doi.org/10.1177/1545968319846120

Harvard University. “Bioinspired Robotics: Smarter, Softer, Safer.” https://www.youtube.com/watch?v=RuLAn3XpYAU&t=9s (2015)

Jeffers, M. S., Karthikeyan, S., Gomez-Smith, M., Gasinzigwa, S., Achenbach, J., Feiten, A., & Corbett, D. (2018). Does Stroke Rehabilitation Really Matter? Part B: An Algorithm for Prescribing an Effective Intensity of Rehabilitation. *Neurorehabilitation and neural repair*, *32*(1), 73–83. https://doi.org/10.1177/1545968317753074

Lang, C. E., MacDonald, J. R., & Gnip, C. (2007). Counting repetitions: an observational study of outpatient therapy for people with hemiparesis post-stroke. *Journal of neurologic physical therapy : JNPT*, *31*(1), 3–10. https://doi.org/10.1097/01.npt.0000260568.31746.34

O’Neill, C., Proietti, T., Nuckols, K., Clarke, M., Hohimer, C., Cloutier, A., Lin, D., and Walsh, C. Inflatable soft wearable robot for reducing therapist fatigue during upper extremity rehabilitation in severe stroke. I*EEE Robotics and Automation Letters,*I 5(3). pp. 3899-3906. (2020).

Proietti, T., O’Neill, C. Gerez, L, Cole, T, Mendelowitz, S, Nuckols, K., Hohimer, C., Lin, D., Paganoli, S., & Walsh, C., Restoring arm function with a soft robotic wearable for individuals with amyotrophic lateral sclerosis.*Science Translational Medicine*.15; 681. (2023).DOI:10.1126/scitranslmed.add1504

Proietti, T., O’Neill, C., Hohimer, C., Nuckols, K., Clarke, M,. Zhou, Y., Lin, D., & Walsh, C. Sensing and Control of a Multi-Joint Soft Wearable Robot for Upper-Limb Assistance and Rehabilitation. *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 2381-2388, (2021)

Proietti, T., Nuckols, K., Grupper, J., Schwertz de Lucena, D., Inirio, B., Porazinski, K., Wagner, D., Cole, T., Glover, C., Mendelowitz, S., Herman, M., Breen, J., Lin, D., & Walsh, C. Combining soft robotics and telerehabilitation for improving motor function after stroke. *Wearable Technologies. 5*, e1. doi:10.1017/wtc.2023.26