Recovery of Function after Stroke:

Robotics & Physiology

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Outline

1. How do people recover motor function after stroke?
   - Major Questions
   - Is there a biological basis for recovery?
   - PET at Wash U.
2. Why Transcranial Magnetic Stimulation?
3. Why Rehabilitation Robots?
   - Robots and Transition to Task Practice
   - Robots and Synchronized Stimulation
   - rsfMRI &TMS as a probe of recovery
4. Future Directions
5. Conclusions

Take-home Messages

- The biological basis for recovery of motor function after stroke is still obscure.
- Arm movements are impaired by stroke and can be improved by mass practice, and explicitly translated into real world activities.
- Transcranial Magnetic Stimulation (TMS) allows functional mapping of the human brain.
- TMS combined with practice has effects that depend on timing.
- Brain connectivity and efficiency may be improved with therapy, particularly as it relates to non-primary motor areas.
- The future of recovery may depend on providing the right combination of stimulation and practice.

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Career guidance, scientific forum, etc.

Subsection 2

Is there a biological basis for recovery?

- Does reorganization of brain function support recovery?
- Does experience shape recovery?
- Is the sub-acute phase a *sensitive* or *critical* period?

Wash. U. in 1995

Residents/Trainees

- Tom Carmichael
- Keith Tansey
- Maurizio Corbetta
- *John McDonald*
- Amy Bastian

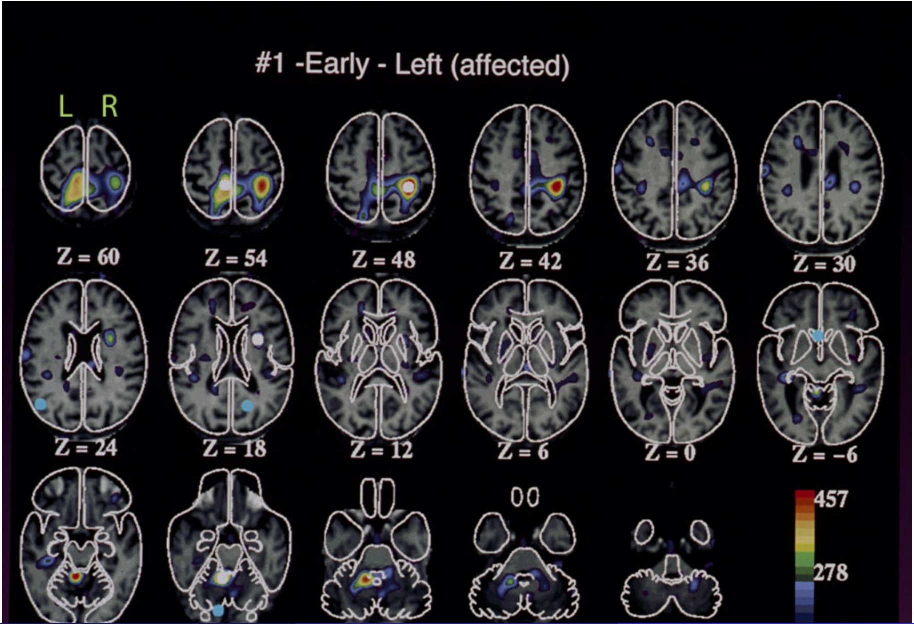
Faculty

- William Powers
- Alex Dromerick
- Mark Raichle
- Tom Thach

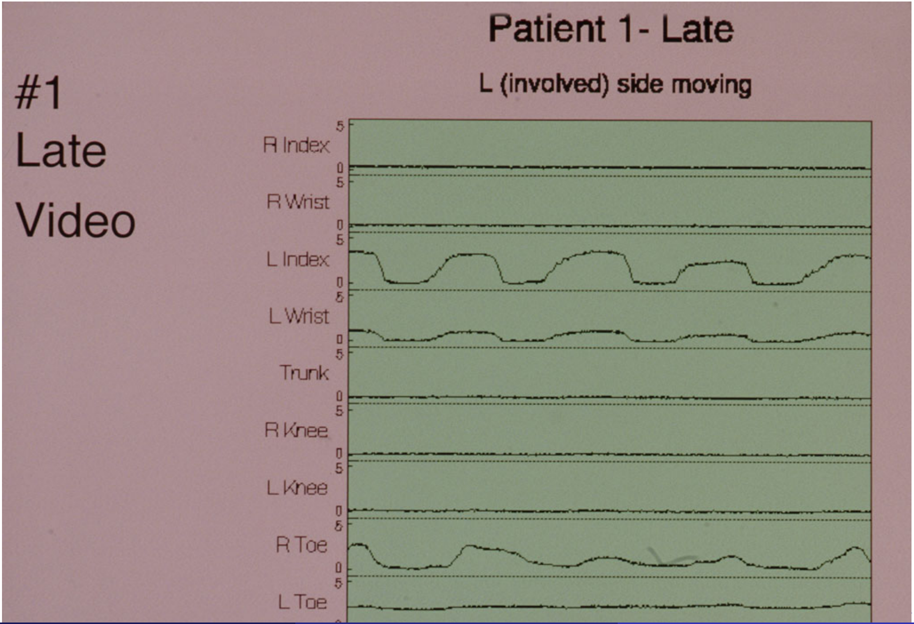
Section 1

How do people recover motor function after stroke?

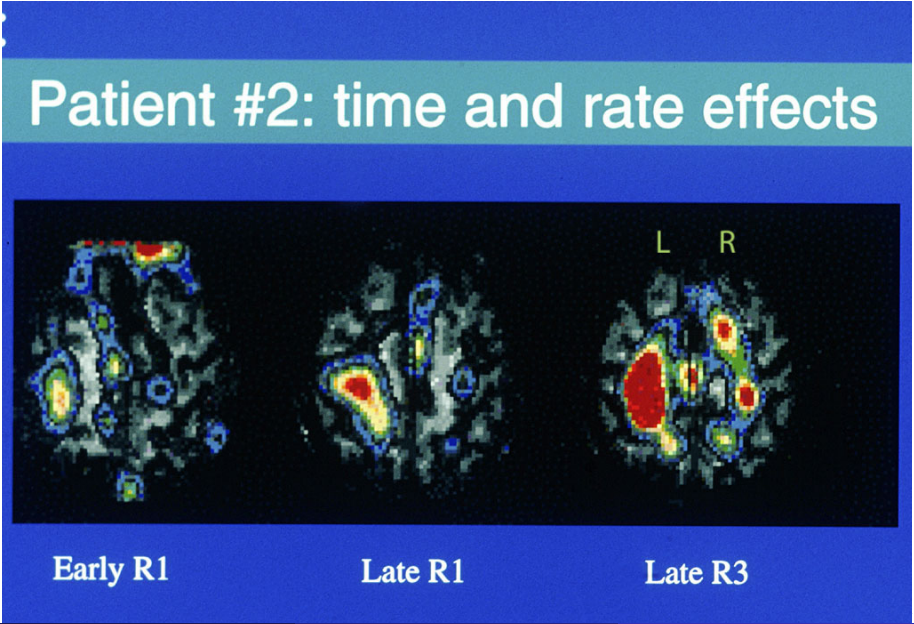
Bilateral Activation?



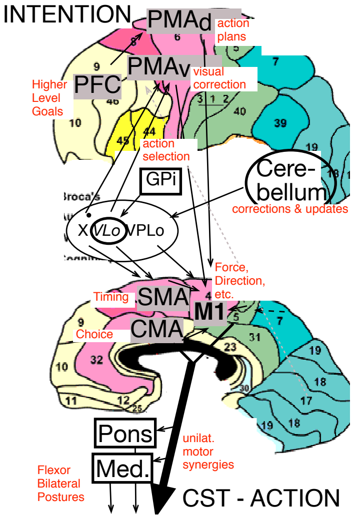
Yes, But...


#1
Late
Video
Patient 1- Late
L (involved) side moving
R Index
R Wrist
L Index
L Wrist
Trunk
R Knee
L Knee
R Toe
L Toe

Effects of Rate and Time



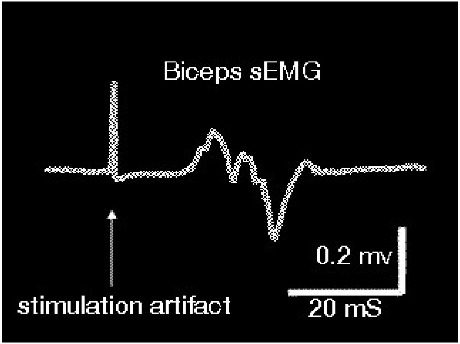
What Happens to Motor Function after Stroke?



Section 2

Why Transcranial Magnetic Stimulation?

TMS of Motor Cortex



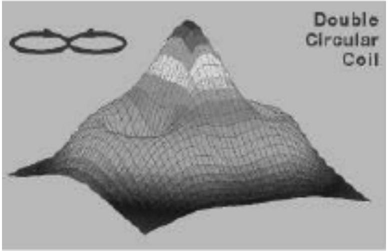
TMS Principle:
Faraday's Law of Induction

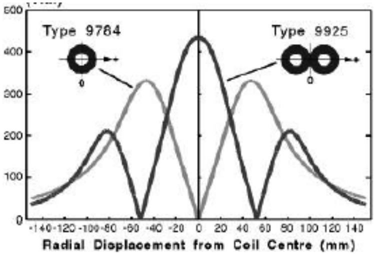
$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

Interpretation: *Curl* of electric field in space opposes a changing magnetic field in time

TMS Practical Issues I

- Magnetic fields cannot be localized deeply versus the surface.





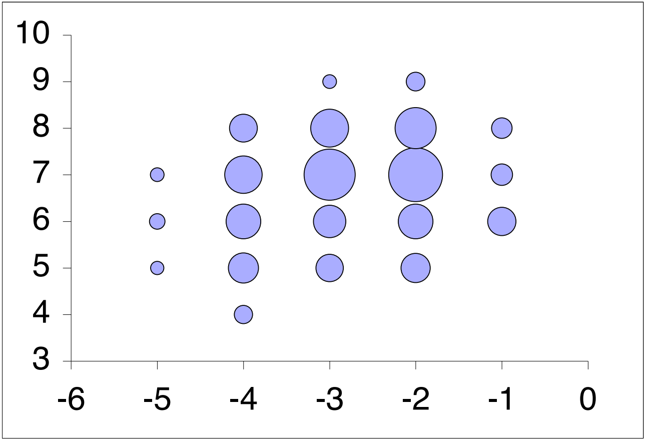
- The better localized in 2D, the weaker the effect.
- But *hyperacuity* can be achieved

Magnetic Stimulation Map Method Example

- Motor evoked potentials (MEP) from hand
- Map acquired at 110% motor threshold on 1 cm scalp grid
- Stereotactic location of TMS coil center
- Two primary map metrics:
  - Center-of-Gravity (COG)
  - Spread: Map volume: Sum of normalized responses at each location

Example Map

Stroke Patient, right EDC map, cm scale

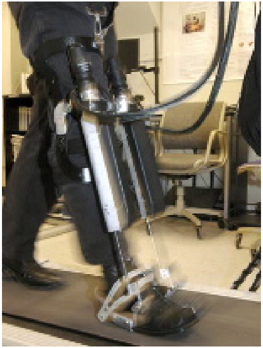


- Inhibit or Interfere with Function
- Modulate Excitability
- Measure Interregional Connectivity
- Condition Circuits during Practice

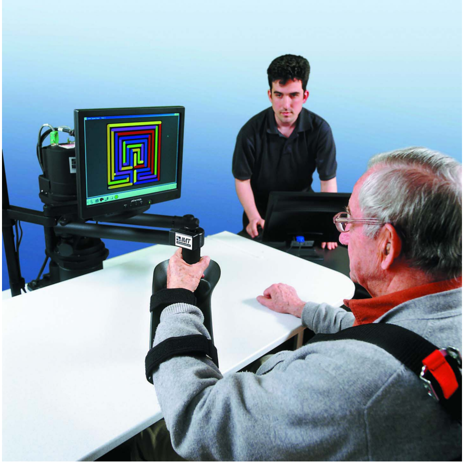
Section 3

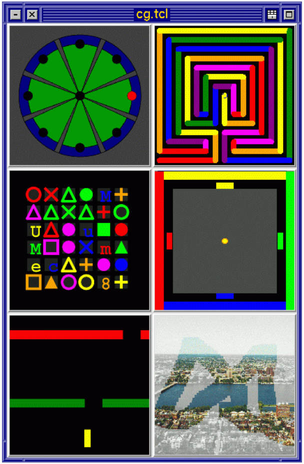
Why Rehabilitation Robots?

Multiple Types

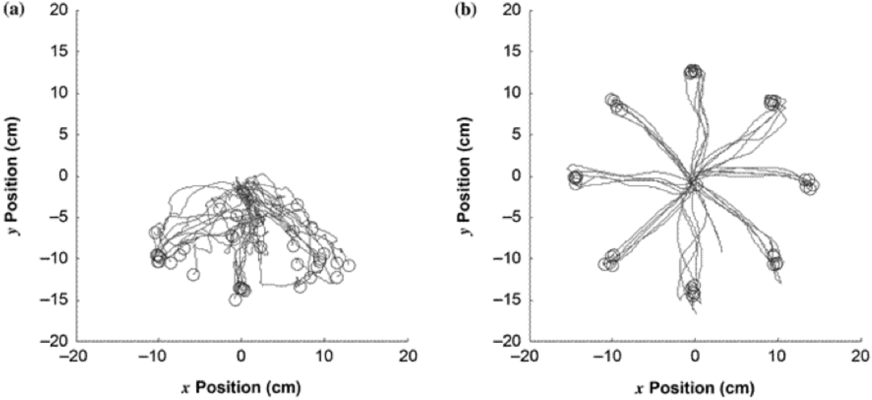


Training Games





Movement Improvement in Chronic Stroke



from Finley MA, et al. 2005

Subsection 1

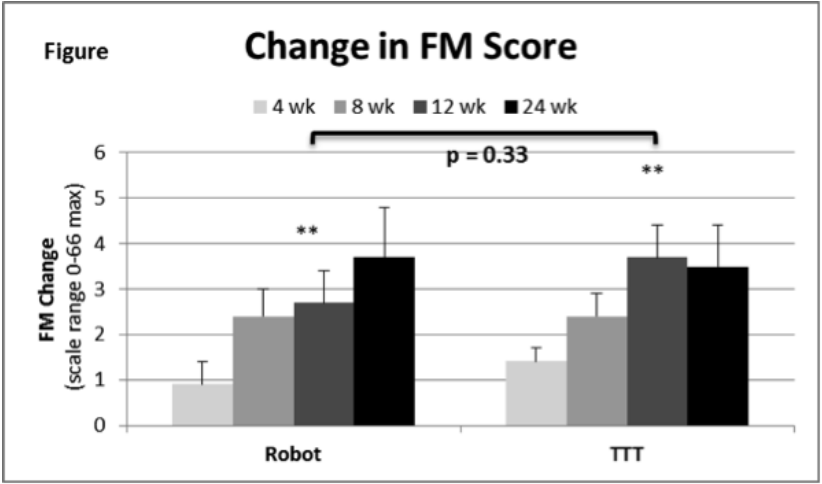
Robots and Transition to Task Practice

Transition to Task Training (TTT) Trial

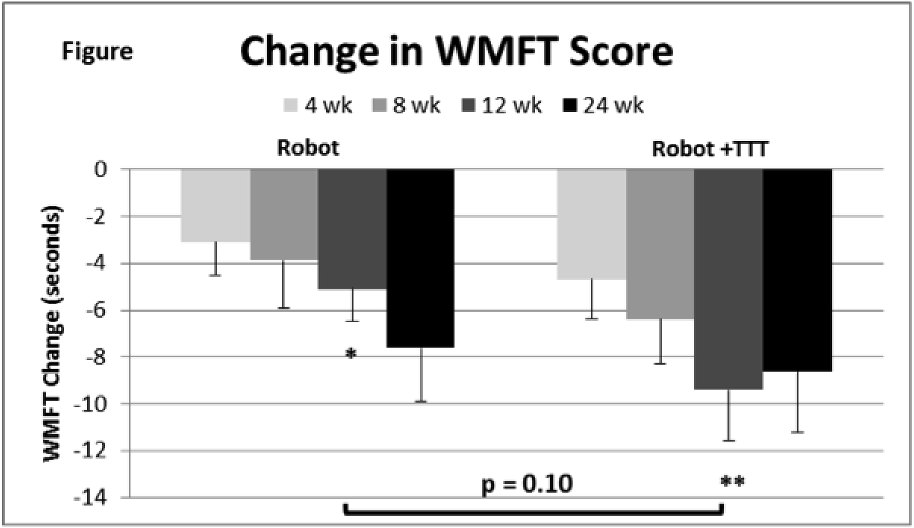
- Replaced last 15 minutes of hour-long session of robotic training (planar/wrist)
- Functionally based real world tasks: within 4 domains:
  1. homemaking
  2. hygiene
  3. feeding
  4. dressing skills
- Fugl-Meyer 7-38 entry crit., Therapy 12 wks., 3 hrs. a wk.

TTT Tools

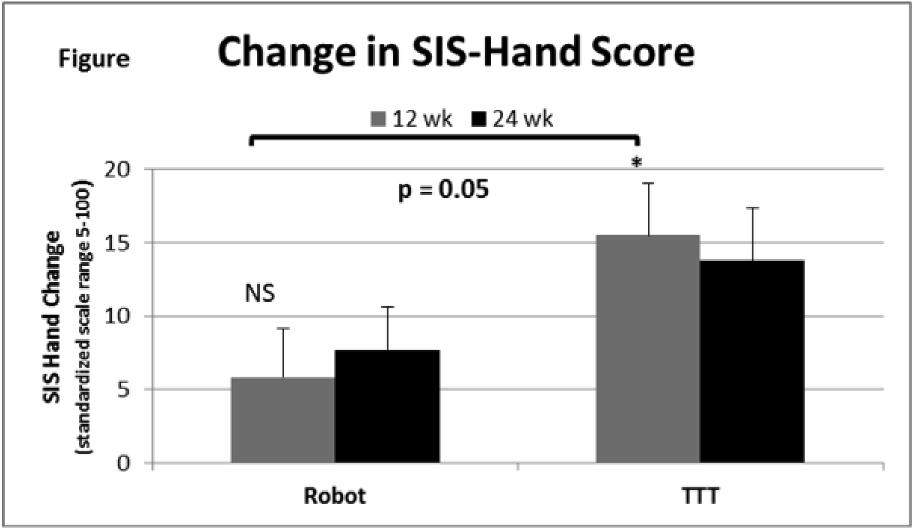
TTT Final Results



TTT Final Results (cont.)



TTT Final Results (cont.)



Subsection 2

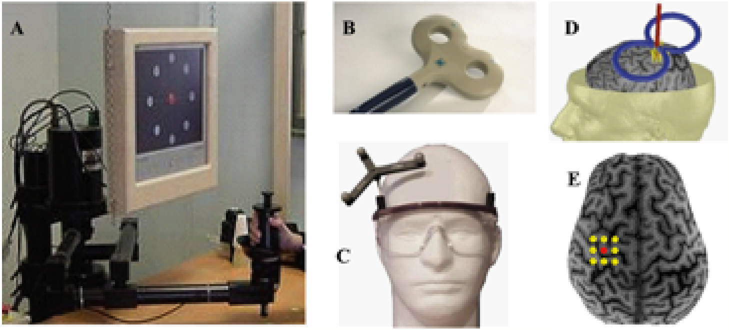
Robots and Synchronized Stimulation

TMS-evoked movements

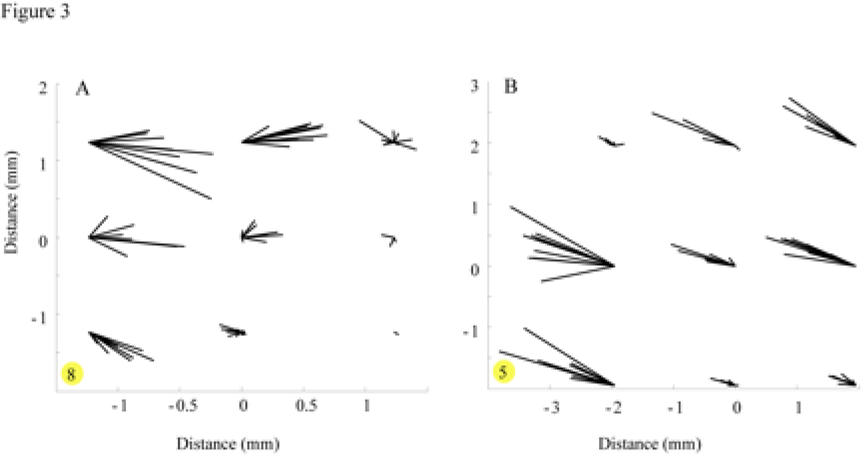
1. Normal subjects with arm at rest in robot
2. Stimulate over virtual 3×3 cm grid
3. Measure movement threshold at most responsive point (hotspot)
4. Measure 10 responses at 120% of mvmt. threshold
5. Spring field to keep handle in center (neutral position) and return handle after mvmt.

Experimental Setup

Figure 1



Conclusions: TMS-evoked movements

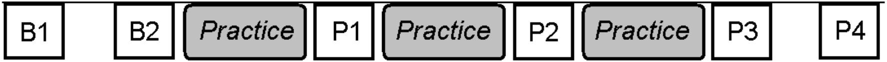


- TMS can evoke proximal arm movements in an arm robot.
- Movement maps varied by subject & by location.
- But movements were consistent within a single stimulation location.

Experimental Design

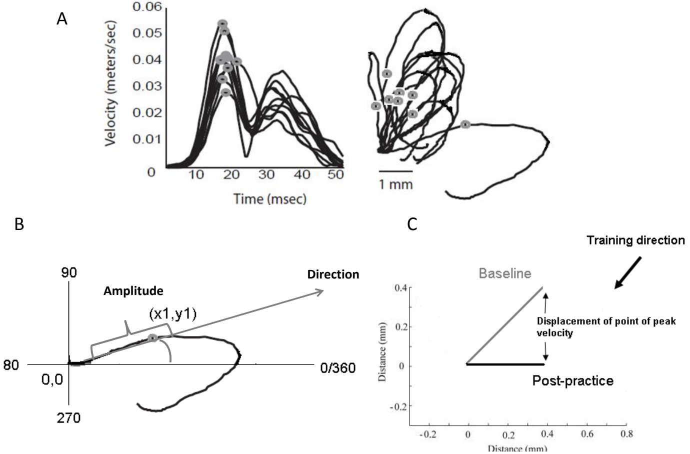
A

B

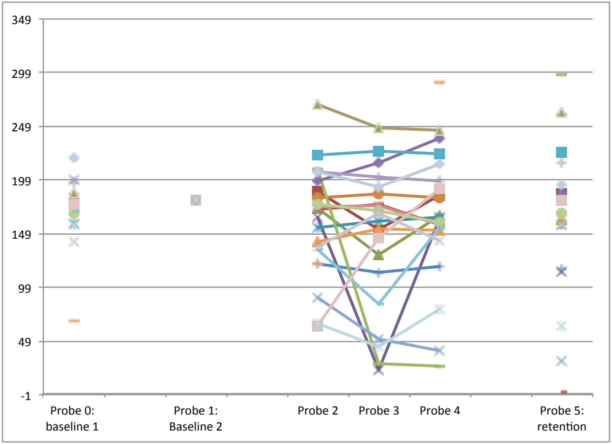


Practice against spring field, passive return to center.

Outcome Parameters



Training Effect on Individuals



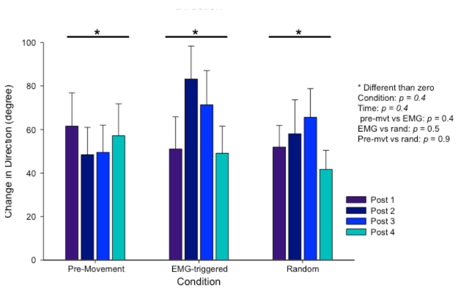
Conclusions: Practice-related plasticity

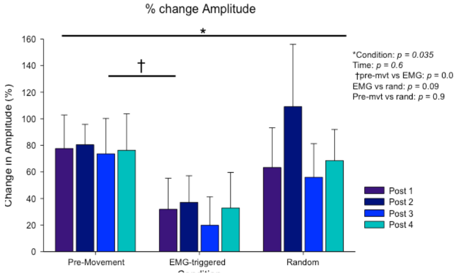
1. $\exists$ some drift in TMS-evoked mvmt., but mvmt. directions & end-points are significantly different after practice.
2. Effects partly explained by change in MEPs – balance agonist/antagonist.
3. More complex than for single distal joint mvmt.
4. More normal participants resistant to practice-related plasticity, which also presents opportunity to test interventions.

Effect of stimulation on plasticity

- NIH-funded study testing low-rate rTMS (0.1 Hz)
- Tests three timing regimens in which some training movement are accompanied by M1 stimulation:
  1. Late reaction time period (150 ms)
  2. Early movement time (EMG-triggered)
  3. Random
- and a control:
  - Sham stimulation (with sham coil)

Timing & Movement Amplitude





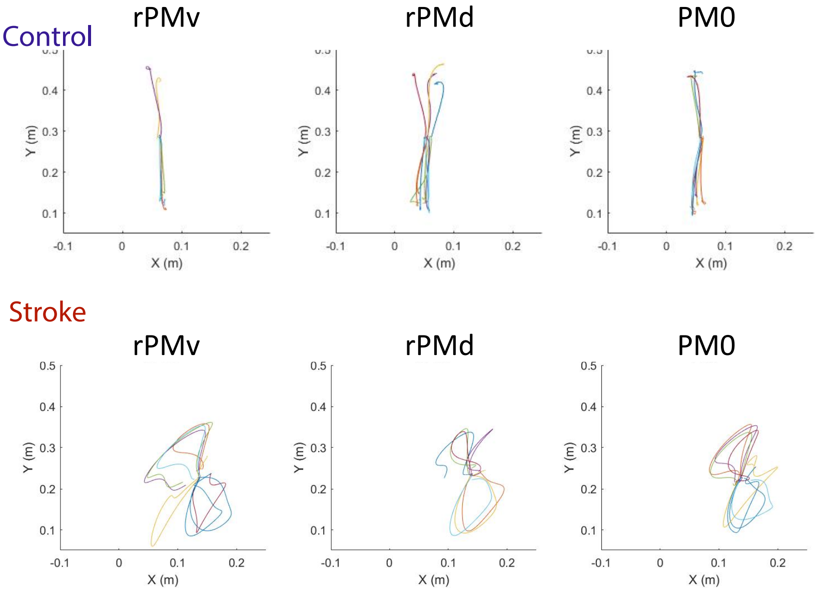
Conclusions: Stimulation Enhanced Plasticity

1. Stimulation affects practice effects in a timing-dependent manner.
   - Late Reaction Time stimulation (150 ms) increases motor output.
   - Early Movement stimulation (EMG triggered) decreases motor output (effect on MEP, not shown) or is less effective.
2. But balance of synergies is not affected by stimulation time.
3. Provides a means to enhance practice effects in stroke.

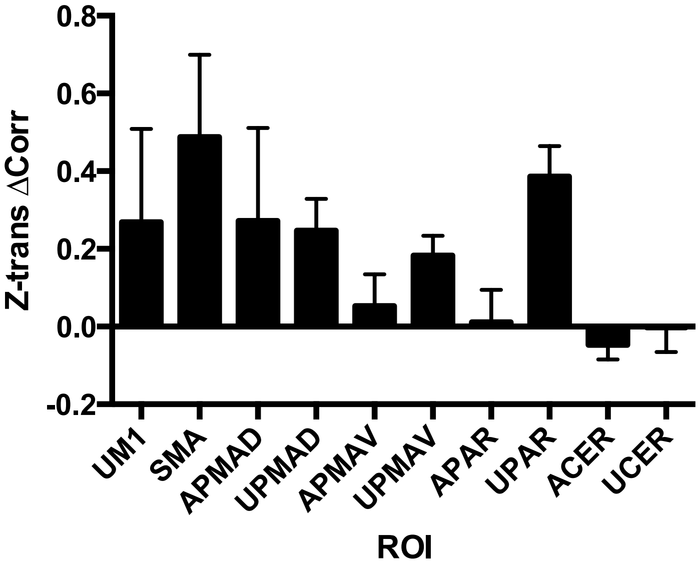
Subsection 3

rsfMRI &TMS as a probe of recovery

TMS Interference with Reaching



Connectivity Δ after Intensive Chronic Stroke Rehab



Section 4

Future Directions

- Plasticity through synchronized stimulation
- Prediction of response to Robot + TTT
- Knowledge Base of Brain Connectivity
- Expand Knowledge of Dynamic Connectivity in Motor Control
- Smart Assistive Devices for Persistent Deficits

Section 5

Conclusions

- Biological basis for recovery of motor function after stroke
- Arm mvmt. impaired by stroke can be improved by mass practice, and translated into real function.
- TMS allows functional mapping of the human brain.
- TMS combined with practice has timing-dependent effects.
- Brain connectivity/efficiency improved with therapy, particularly as it relates to non-primary motor areas.
- The future of recovery may depend on providing the right combination of stimulation and practice.