Give the Brain a Hand

Session No.: SC 253
Wednesday, April 08, 2016
10:00 - 11:00 AM
AOTA Conference, Chicago
Guy McCormack, Ph.D., OTR/L,FAOTA

Short Biography

Guy L. McCormack, PhD, OTR/L, FAOTA is a teacher, practitioner, and researcher. He teaches courses at Samuel Merritt University on conditions of dysfunction, promotion of wellness and health promotion, administration and research.

Goals of the Presentation

Goal 1
Review the Neuroscience Evidence on the Hand's Influence on the Development of the Brain

Goal 2
Describe Some Principles of Experience-Dependent Neuroplasticity

Goal 4
Discuss Examples Promising Interventions for Occupational Therapy Practice

Emerging Paradigm Shifts in Rehabilitation

"Triple Aim": Reducing costs, improving population health, and improving the patient experience.

Introduction

1. There is a common belief in occupational therapy that through the use of our hands one can influence their state of health (Mary Reily, 1961).
2. Neuroscience has supported this premise by demonstrating that neuroplasticity does occur in the cerebral cortex in conjunction with somatosensory stimulation of the hands in both humans and primates.

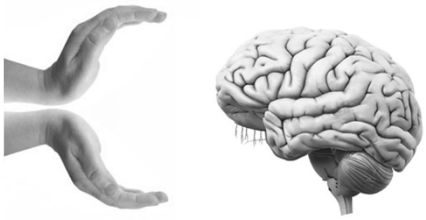
Introduction

3. There is also strong evidence that continuous and long lasting participation in tactile or sensorimotor skills with the hands results in substantial changes (expansion) in the corresponding regions (maps) of the cortex (Recanzone, Merzenich &Dinse,1992;

The Hand and Brain Work Together

Stimulation to the Hand Can Influence the Brain

How Have the Hands Developed the Brain?



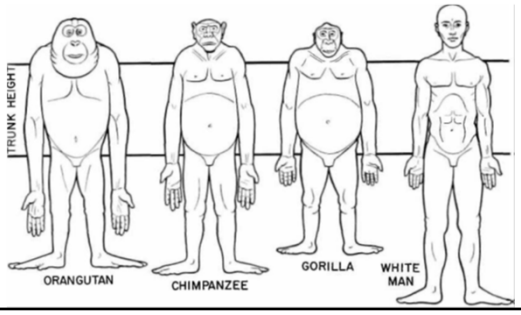
Evidence from Anthropology (Hobbit Human)

Their forehead was sloping. Their brain size was tiny, their hands were small compared to humans today.

2 million years old hand of an ancient ancestor

Evolution of the Hand

Has our intricate and elaborated nervous system with a hand free to perform occupations expanded our brains?



Brodmann Published his Maps of Cortical Areas in Humans, in 1909

Santiago Ramon y Cajal 1913

Harsh Decree:

"Once the brain has suffered insults due to aging, injury, or disease, there is little hope of change or repair because the neuronal pathways are static"

Figure 2.5
Santiago Ramón y Cajal (1852-1934). (Source: Finger, 1994, Fig. 3.26.)

Dr. Wilber Penfield's Study- 1930's

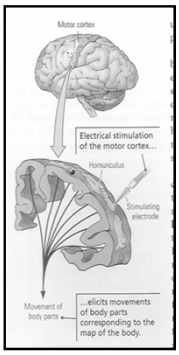
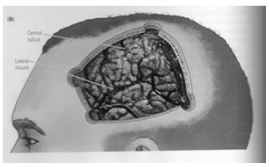


Photo credit: The Canadian Medical Hall of Fame



Helen Keller

Vibratory sensations, as perceived by the hand, are of importance in teaching the deaf to speak. By placing one hand on the larynx of a speaker and the other hand on his own larynx, a deaf-mute learns the vibration patterns of speech sounds.

When the patterns "heard" by his left and right hand are identical, the student has succeeded in imitating the sound.

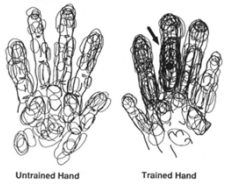
MICHAEL MERZENICH, PhD

- Pioneer in Neuroplasticity in topograhic changes in the cortex due to hand stimulation.
- Developed cochlear implants; often referred to as “bionic ears.”

Stimulation of the Hand Causes Changes in the Cortex

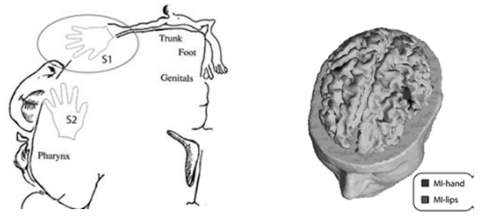
Reorganization induced by training a monkey in a behavioral task produced changes in cortical representation and improved acuity

Monkey Hand



Recanzone,GH , Merzenich,M
Jenkins MW (1992). Topographic reorganization of the hand representation in cortical area 3b owl monkeys trained in a frequency-discrimination task. JN Physiology May 1992 vol. 67 no. 5 1031-1056

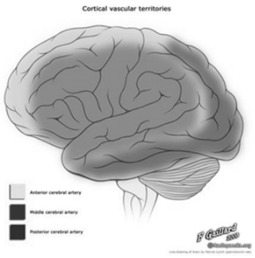
Cortical Mapping & Imaging



New studies show the hand is more closely aligned to the Face and Pharynx

Stroke Rehabilitation

- 5.8 million people living with Stroke.
- Approximately 90% will walk again.
- Only 50% regain functional arm use.
- Only 20% achieve good arm and hand use.



Harvey, R. (2009). Improving Poststroke Recovery: Neuroplasticity and Task-Oriented Training.Current Treatment in Cardiovascular Medicine.11: 251-259.Springer

Systematic Reviews

- Following stroke, up to 85% of patients have hemiparesis, sensory perception and/or motor function impairments of the upper limb in the acute stage.
- Six months post-stroke, only 5% to 20% of these patients show a complete functional recovery and 30% to 60% remain with a non-functional paretic arm.

Doyle S, Bennett S, Fasoli SE, McKenna KT. Interventions for sensory impairment in the upper limb after stroke. The Cochrane Database of systematic reviews 2010;6:CD006331. PMid:20556766

Norman Doidge, MD (2007)

"The discovery that our thoughts can change the structure and functions of our brains is the most important breakthrough in neuroscience in four centuries."

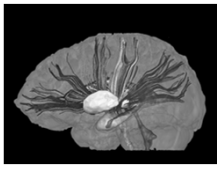
The Brain that Changes Itself. New York, NY: Penguin books

Randy Nudo, PhD, Director of the Landon Center on Aging University of Kansas.

Simple repetitive movements may not be as effective as a type of movement that is constantly challenging the brain.

Randy Bruno, PhD, Neuroscientist Kavli Institute for Brain Science at Columbia, University

"Neuronal connections bridging the thalamus to the cortex are not only massively plastic, but they grow and retract rapidly in only a few days in response to different sensations".



What is Neuroplasticity?

- Refers to the ability of neurons, neural circuits, and the brain itself to be modified and to reorganize both physically and functionally.
- Neuroplasticity can be induced via experience dependent or activity dependent, or persistent stimulation.

Francis, J. Song,W. (2011) Neuroplasticity of the sensory motor cortex during earning.Neural Plasticity. Doi:10.1155/2011/310737

Definition

Experience-Dependent Neuroplasticity is an umbrella term that encompasses both synaptic plasticity and non-synaptic plasticity—it refers to changes in neural pathways and synapses due to changes in behavior, environment, neural processes, thinking, emotions, as well as changes resulting from bodily injury.

** Learning is Essential to Rehabilitation **

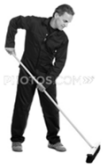
Paradigm Shift

- Glen Gillen, Ed.D, OTR/L FAOTA

Neurodevelopmental interventions are ***not well*** supported by outcome studies.

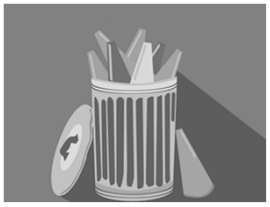
Promotes the **Task-Oriented Approach**

Task-Oriented Training



To Cone or Not to Cone?

Jan Davis, MS, OTR/L



Activity-Dependent Plasticity

Jan Davis, MS, OTR/L

Activity-Dependent Plasticity

1. Goal Driven
2. Task Oriented
3. Involves problem solving
4. Done in a stimulating environment.
5. Real world relevance

Richard L. Harvey, MD
The Rehabilitation Institute of Chicago

Task-Oriented Training

1. Specificity of training
2. Constrained use of impaired limbs
3. Repetition
4. Shaping of skill
5. Saliency of task
6. Knowledge of performance results

Classification of Interventions

Compensatory Training

- **Used for the person who has severe limitations.**
- **Uses adaptive technology to conserve energy and adjust to the environment**
- **Assistive devices, orthotics, prosthics.**
- **Compensation circumvents the problem!**

Remediation Training

- **Restoration of function or skill**
- **Decreases impairments**
- **Assumes cortical reorganization takes place.**
- **Assumes there is a transfer of learning.**
- **Improved task performance will be carried over to improve performance in daily activities.**

Brain Imaging, Neuroscience and Technology

Levin, HS (2006). Neuroplasticity and Brain Imaging Research: Implications for Rehabilitation.
Arch Phys Med Rehabil. 87(12 Suppl2): S1

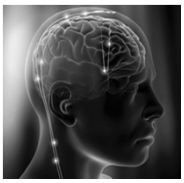
Diffusion Tensor Imaging

- Image Shows Corpus Callosum White Matter Pathways.

Frey,S (2015). University of Missouri, Brain Imaging Center.

The Brain is Extremely Plastic

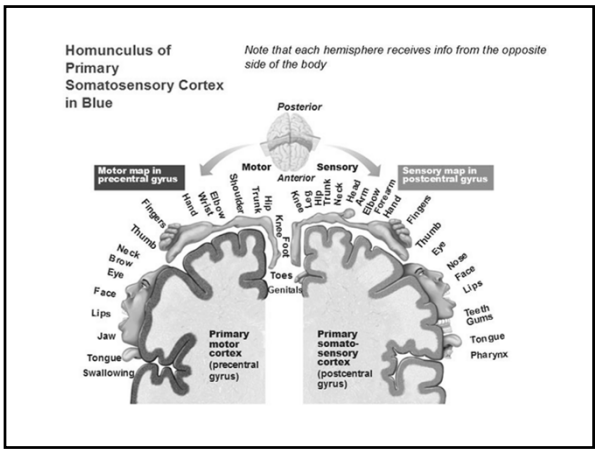
"The brain continuously remodels its neural circuitry in order to encode new experiences and enable behavioral change."

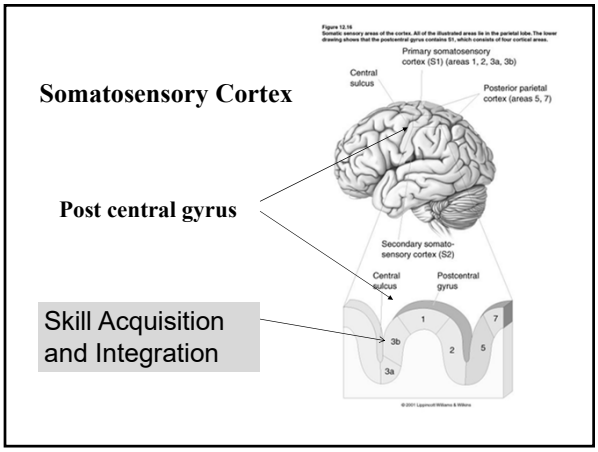


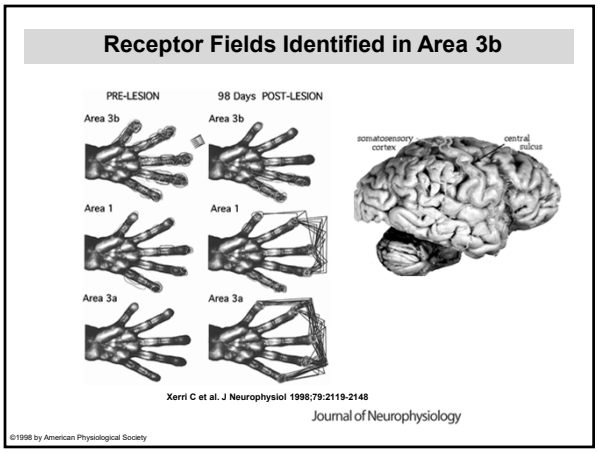
Homunculus Figure Corresponds to the Number and Density of Neurons

Speech Formation

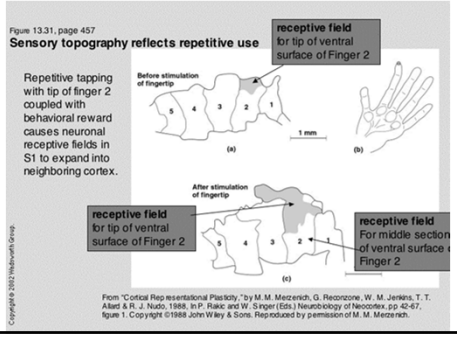
Digital Exploration


Homunculus of Primary Somatosensory Cortex in Blue
Note that each hemisphere receives info from the opposite side of the body
Posterior
Anterior
Motor
Sensory
Motor map in precentral gyrus
Sensory map in postcentral gyrus
Fingers
Hand
Wrist
Elbow
Shoulder
Trunk
Hip
Knee
Foot
Toes
Genitals
Thumb
Neck
Brow
Eye
Face
Lips
Jaw
Tongue
Swallowing
Head
Arm
Forearm
Eye
Nose
Teeth
Gums
Pharynx
Primary motor cortex (precentral gyrus)
Primary somato-sensory cortex (postcentral gyrus)

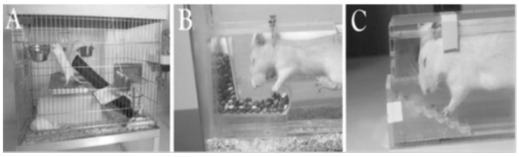

Somatosensory Cortex
Post central gyrus
Skill Acquisition and Integration
Primary somatosensory cortex (S1) (areas 1, 2, 3a, 3b)
Central sulcus
Posterior parietal cortex (areas 5, 7)
Secondary somato-sensory cortex (S2)
Central sulcus
Postcentral gyrus
1
2
3b
3a
5
7


Receptor Fields Identified in Area 3b
PRE-LESION
98 Days POST-LESION
Area 3b
Area 1
Area 3a
Area 3b
Area 1
Area 3a
somatosensory cortex
central sulcus
Xerri C et al. J Neurophysiol 1998;79:2119-2148
Journal of Neurophysiology
©1998 by American Physiological Society

Repetitive Stimulation Enlarges Cortical Maps

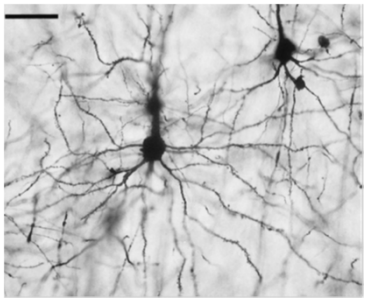


Enriched Environments



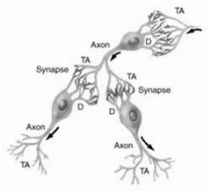
Biernaskie, J. and Corbett , D. (2001). Enriched Rehabilitative Training Promotes Improved Forelimb Motor Function and Enhanced Dendritic Growth after Focal Ischemic Injury. Division of Basic Medical Sciences, Faculty of Medicine, Memorial University of Newfoundland, St. John's

Enriched Environments Increased Dendritic Growth



Environmental Stimulation Increases Dendritic Growth, Connectivity and Promotes Synaptic Transmissions

Dr. Roseanne Schaaf



Dr. Shelly Lane

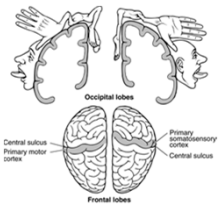
Lane, S & Schaaf, R.C. 2010;

Intensity Matters

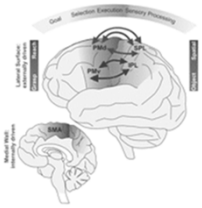
In animal models who were trained on a skilled reaching task to perform 400 reaches increased in synaptic connections when compared to 60 reaches. Low-intensity training can weaken synapses.

Cortical Reorganization

Motor and Sensory Brain Mapping

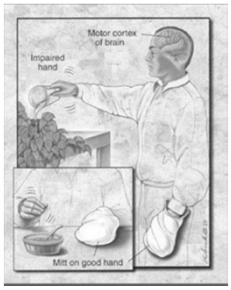


Hand Actions



Forced Use is Better than Compensation

Constraint Induced Movement Therapy (CIMT) consists of an intensive upper limb exercise program, coupled with placing the unaffected arm in a restrictive mitt to encourage use of the weak upper limb for 3-6 Hours per day.



Wolf et al, 2006 JAMA

Cutaneous Anesthesia of the Forearm

- Has recently been found to improve sensory and motor function of the paretic hand in chronic stroke patients.
- Topical anesthesia cream (EMLA) or placebo was applied to their uninvolved forearm, dexterity in involved arm improved to a greater extent.

Citations

1. Bjorkman A, Weibull A, Rosen B, et al. (2009).Rapid cortical reorganization and improved sensitivity of the hand following cutaneous anesthesia of the forearm. Eur J Neurosci 29: 837–844.

2. Petoe, MA, Molina Jaque,FA, Byblow, WD, Stinear,CM (2012). Cutaneous anesthesia of the forearm enhances sensorimotor function of the hand. Journal of Neurophysiology: 109 (4),1091-1096 DOI: 10.1152/jn.00813.2012

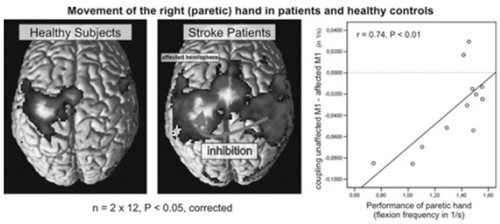
Rapid Experience-Dependent Plasticity Years after Stroke

This study showed the maps in brain-damaged individuals are actually much more plastic than those without damage.

The stroke patients reported a shift in localization judgment sensing the touch farther down their finger, toward the wrist.

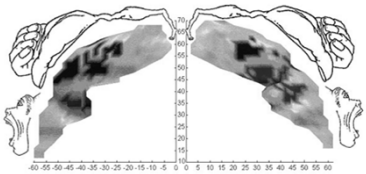
Jared Medina & Brenda Rapp (2014). Rapid Experience-Dependent Plasticity following Somatosensory Damage. Curr Biol 17:24(6): 677-80.

Influences of Stroke

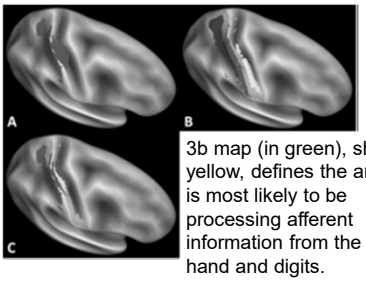


Reorganization of the Somatosensory

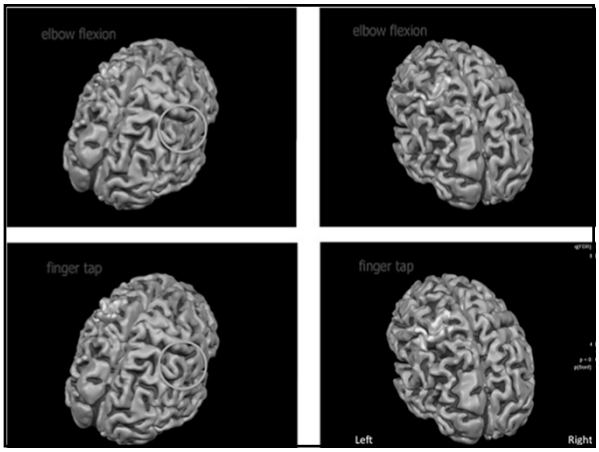
Stroke provokes a transient enlargement of the hand representation that normalizes as hand functions are regained.



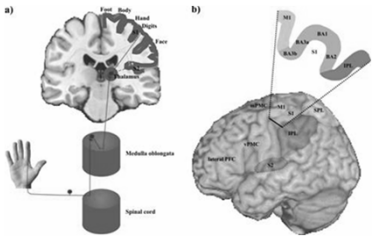
Somatosensory Cortex



3b map (in green), shown in yellow, defines the area that is most likely to be processing afferent information from the left hand and digits.
Bogdanov, 2012

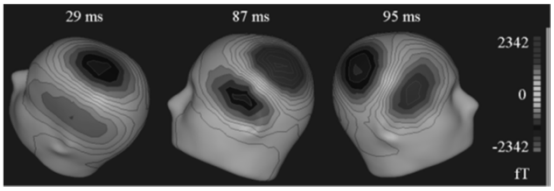


Digital Stimulation

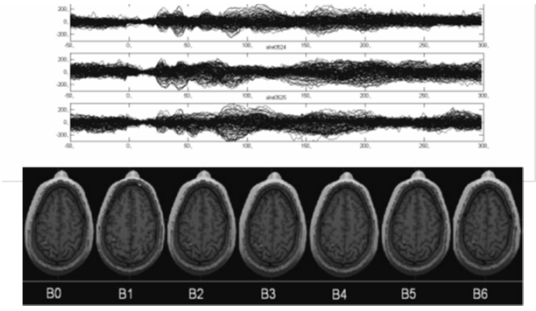


http://edoc.hu-berlin.de/dissertationen/preuschhof-claudia-2008-11-28/HTML/image001.jpg

Distribution of Magnetic Fields as Measured on the Scalp during an Electric Stimulation of the Right Hand

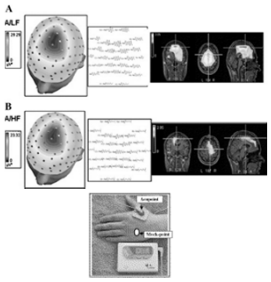


Magnetoencephalography (MEG Measurements Display Wave Forms Elicited by the Stimulation of the Index Finger



Acupuncture and EEG

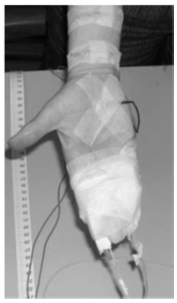
- Twelve healthy males experienced Acupoint stimulation at LI 4 and a sham Acupoint 4th interosseous muscle.
- Decreased Theta activity was detected at FZ at cingulate cortex which is known to inhibit nociceptive processing in the brain.



Chen,A. Liu,F & Nielsen,L (2006).Mode and site modulation of the human brain. Neuoimage
29(40 p.1080-1091

Finger Binding

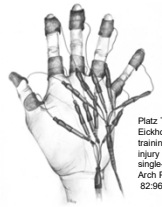
- The total duration of the session sums to 5.5 hours.
- Produced rapid and statistically significant changes in cortical representation.
- Changes in synaptic connections (LTP/LTD).



Two Weeks of Passive Sensory Stimulation

Neuromuscular Electrical Stimulation

20 min Sensory Stimulation



Platz T, Winter T, Müller N, Pinkowski C, Eickhof C, Mauritz KH (2001). Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: a single-blind, randomized, controlled trial. Arch Phys Med Rehabil 82:961-8.

60 min Arm Ability Training

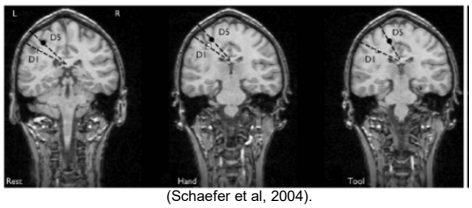
Manipulating Objects with the Hands Influences the Cortex

fMRI Studies are showing measurable changes in Cortical Maps occur with the manipulation of objects in a repetitive manner.

Hallet, M (2005). Neuroplasticity and Rehabilitation. JRRD,42,4,211-17

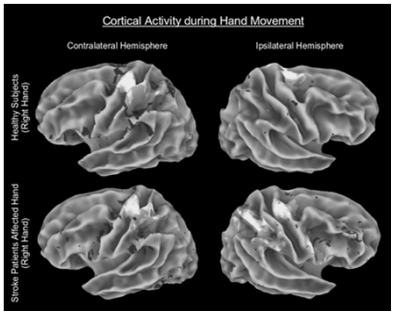
Cortical Mapping with Use of Tools

This Scan shows an increase of the three-dimensional distance between D1 and D5 after tool use in humans



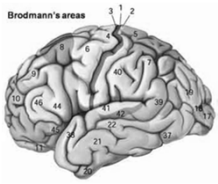
(Schaefer et al, 2004).

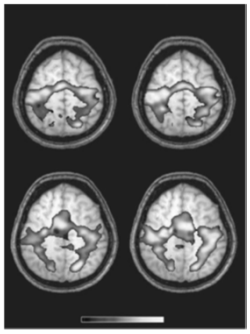
Functional Magnetic Resonance Imaging (fMRI) During Right Hand Activity



Cortical Reorganization

Use of a Body Part Enhances Its' Representation on Cortical Maps



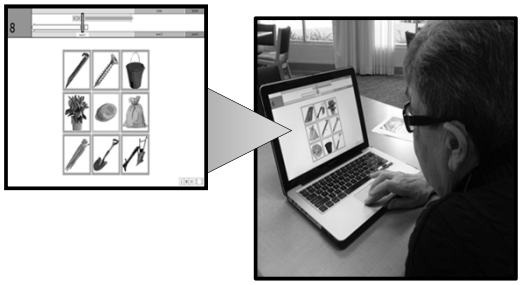


fMRI Studies and Finger Tapping

- Cortical Map Representation corresponds to finger usage and stimulation.
- More complex patterns of finger tapping facillated more neurons than sequential tapping pattern

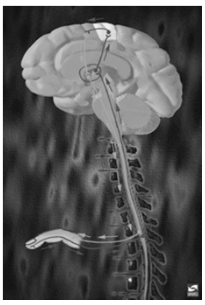
Duncan, RO & Boynton (2007). Tactile Hyperactivity Thresholds Correlate with Maps in Primary Cortex Cerebral Cortex Journal

Virtual Context



Braille Studies and fMRI

Sensory stimulation has direct influence on Neurons in the Postcentral and Precentral Cortex

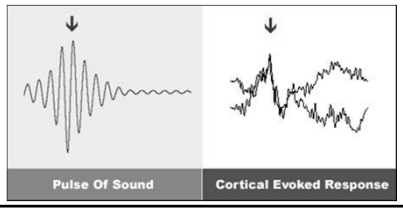


“Neurons that fire together, wire together”

Donald Hebb, 1949

Event Evoked Potential

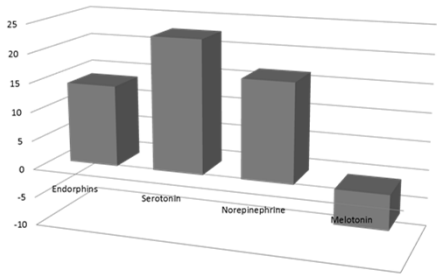
When the brain is given a stimulus, through the ears, eyes or tactiles senses, it emits an electrical charge in response, called a Cortical Evoked Response (shown below).



Audio-Visual Entrainment

- Increased Cerebral Blood Flow
- EEG Normalization
- Neurotransmitter release
- Music & Flashing Lights

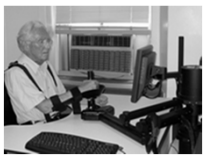
Neurotransmitter Changes



Robot-Aided Consolidation

Clinical scales suggest that robot-aided sensorimotor training ***does*** have a positive effect on the reduction of impairment and the reorganization of the adult brain.

- Krebs, H. Volpe, B Aisen, M; Hogan,N (2000). Increasing productivity and quality of care: Robot-aided neuro-rehabilitation. Journal of Rehabilitation Research and Development Vol. 37 No. 6,

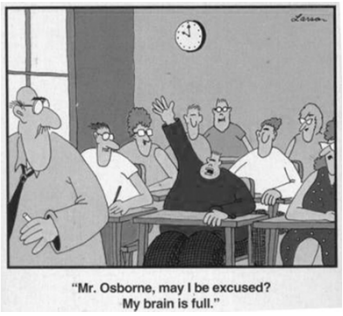


Robotic devices guide the user through the movements.

Rhythmic Auditory Cueing

Studies show that bilateral rhythmic and auditory cueing improves motor function in participants 20 years post-stroke.

The Brain has a Limited Capacity



Prosthesis Printed in 3-D

It takes 25 hours to print 285 layers & 30 pieces to make up the hand.

E-nable Company

http://enablingthefuture.org/get-involved/

Build a Hand

http://enablingthefuture.org/upper-limb-prosthetics/

Eye Hand Tracking

Bi-Lateral Hand Transplant

- It took a 40-member team who conducted the 10-hour operation on 8 year old Zion.
- "One component that's ongoing but started very early was making sure he felt comfortable with the idea of having new hands, looking at and connecting with them,"

Todd Levy, MS, OTR/L,

Lego Serious Play

"It unleashes creative energies, modes of thought and ways of seeing that most adults have forgotten they even possessed."

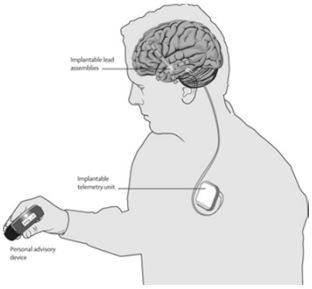
https://www.linkedin.com/pulse/give-your-brain-hand-dieter-reuther

Do Cell Phones Have the Answer?

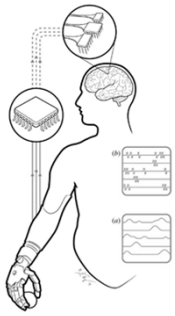
Application "Brain in Hand" provides people with personalized support from an app on their phone.

http://braininhand.co.uk/#sthash.ID9VxvmF.dpuf

Prosthetic Memory?



Microsimulation of the Cortex



Electrical stimulation is being used in animals and humans to study potential links between neural activity and specific cognitive functions.

Neurobridge System SCI

A small chip implanted in the patient's motor cortex transfers signals from the brain to an external computer that recodes brain signals into electrical impulses for controlling a sleeve worn on the wrist.

http://sciencebusiness.technewslit.com/?p=18011

Neurogenesis in the Hippocampus

- Thousands of new cells are produced each day; many new neurons die off.
- **Active learning i.e.** New activities (hobbies, sports, languages)stimulate retention of the new neurons.

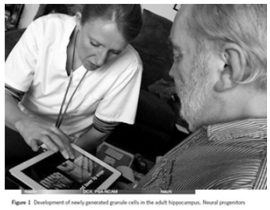
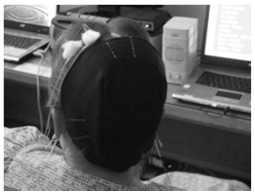


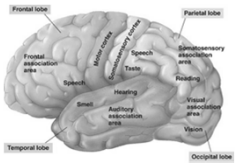
Figure 1 Development of newly generated granule cells in the adult hippocampus. Neural progenitors

Electrodes Placed Over Pre-Central Gyrus (Motor Strip)- C3

Moved Electrodes over the Somatosensory Gyrus

Presumably sensory neurons were recruited and facilitated.



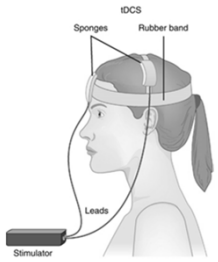


Vibration to Specific Fingers

Qualitative Findings

- “Tingling” in Right leg correlated with CZ
- “Itchiness” and more sensation in Right Arm
- Right arm less “stiff” correlated with C3
- Improved Arousal during the day
- Edema subsided in right dorsum of hand
- Liability changes “cries with tears”
- Improved word finding and speed of verbal response, able to converse in groups.
- Improvements in Receptive and Expressive Speech
- Reading short novels – 4 months after TX

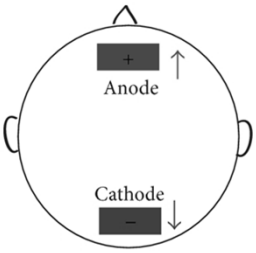
Transcranial Direct Current Stimulation (tDCS)



- Stimulation to the motor cortex (M1) reduces neuropathic pain.
- Forty Percent (40%) responded positively.
- Reduction of pain intensity by at least 20%.

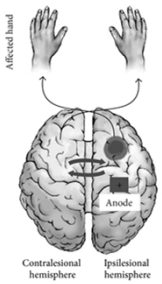
O’Neil F, Sacco, P, Nurmikko,T (2015). Evaluation of tDCS . Trails ISRCTN5639387

Anodal tDCS has an Excitatory Effect on the Local Cerebral Cortex



Anodal stimulation increases subsequent spike activity by lowering the membrane potential, whereas cathodal stimulation reduces subsequent spike activity in the stimulated area by increasing the membrane potential. tDCS promotes LTP in motor cortical slices.

Balance the Level of Hemispheric Excitability



Interhemispheric competition following a stroke. The model suggests that the contralesional (unaffected) motor region exerts an excessive inhibitory influence on the ipsilesional (affected) motor cortex which might limit poststroke motor recovery.

Transcranial Direct-current Stimulation

Right and Left Hand differences

The right Hand has a shorter palm and longer fingers

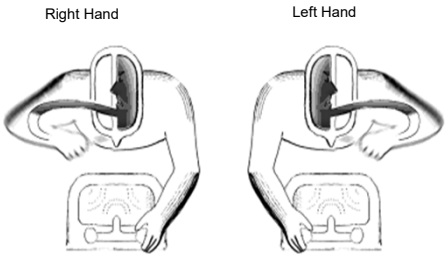
Sword and Shield Theory

Soldiers who held a sword in their right hand could better protect their(left-sided)heart with their shield.

Citation

Andrea Gomez Palacio Schjetnan, Jamshid Faraji, Gerlinde A. Metz, Masami Tatsuno, and Artur Luczak (2013). “Transcranial Direct Current Stimulation in Stroke Rehabilitation: A Review of Recent Advancements,” Stroke Research and Treatment, vol. 2013, Article ID 170256, 14 pages, 2013. doi:10.1155/2013/170256

Switching Hemispheres



10,000 Hours to become an Expert

QUESTIONS?