Neuroplasticity As A Basis For Rehabilitation

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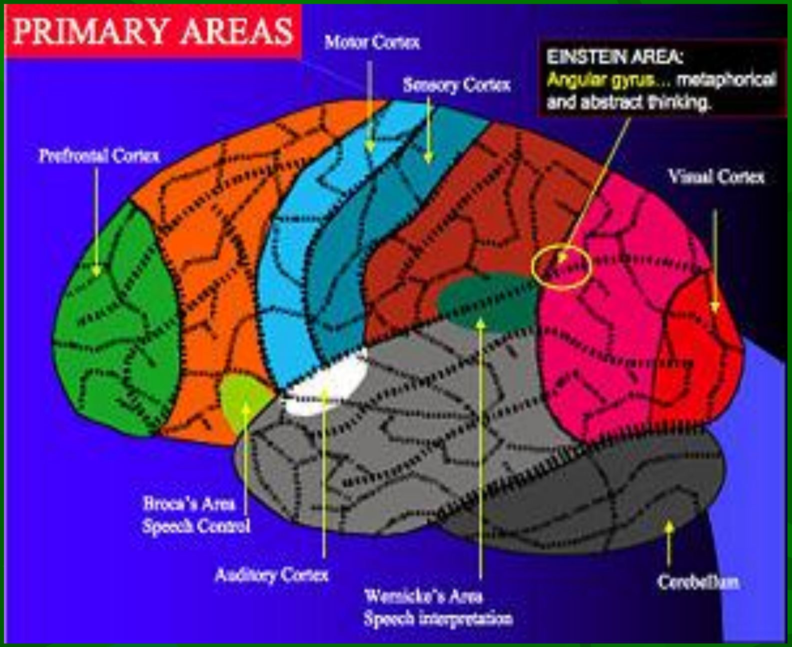
What is Neuroplasticity?

- The brain's ability to reorganize itself forming new neural connections throughout life.

Definition from:
http://www.medterms.com/script/main/art.asp?articlekey=40362

Image from
http://en.wikipedia.org/wiki/Neuroplasticity

- Neuroplasticity challenges the idea that brain functions are fixed in certain locations

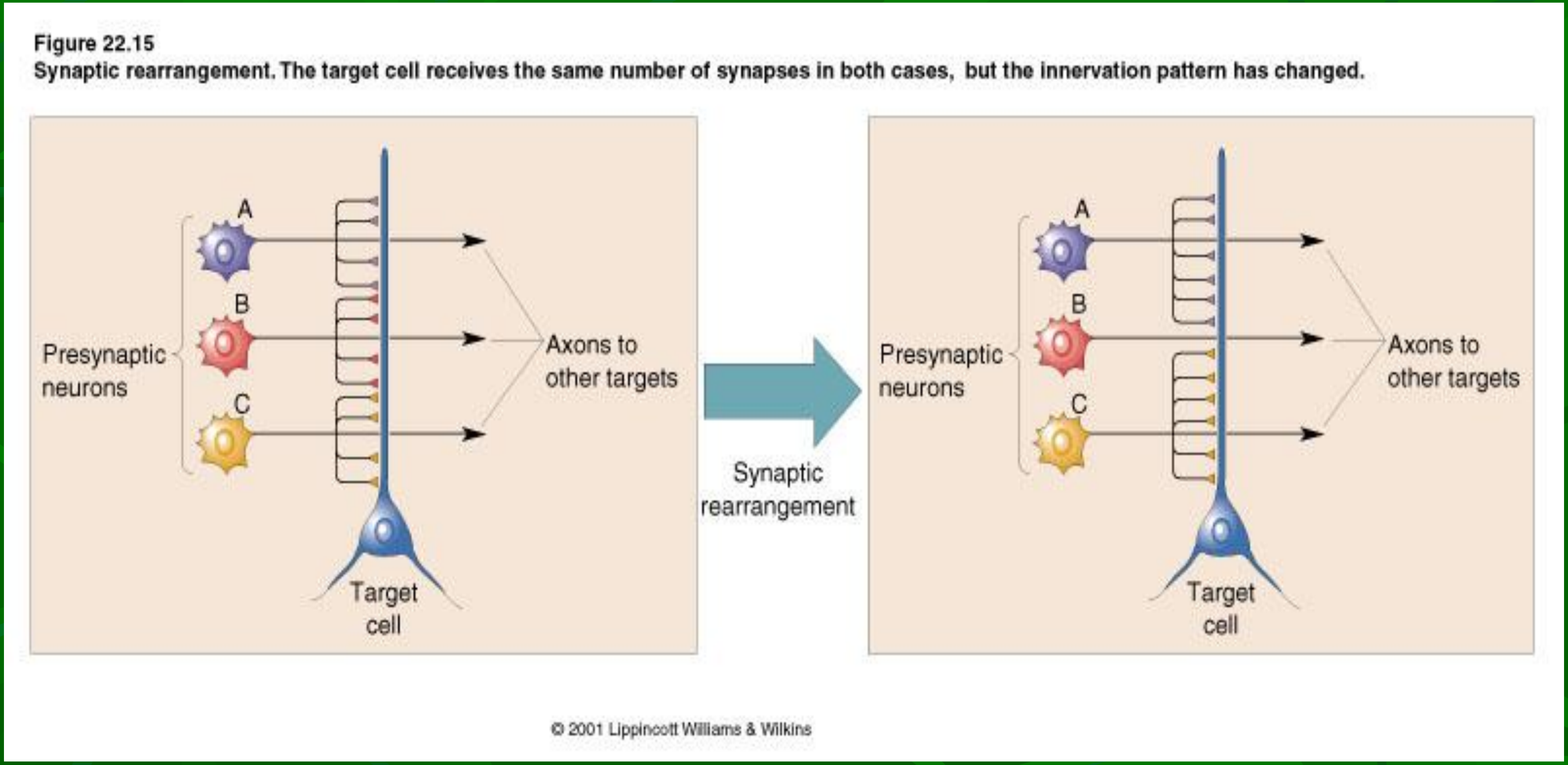


Mechanisms of Neuroplasticity

- Making use of pathways previously functionally inactive
  - e.g., activation of previously silent synapses

- “Axonal sprouting" from surviving neurons to create new pathways

Mechanisms of Neuroplasticity
-- Synaptic Rearrangement



Bear MF, Connors BW, Paradiso MA. Neuroscience: Exploring the Brain, 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2001.

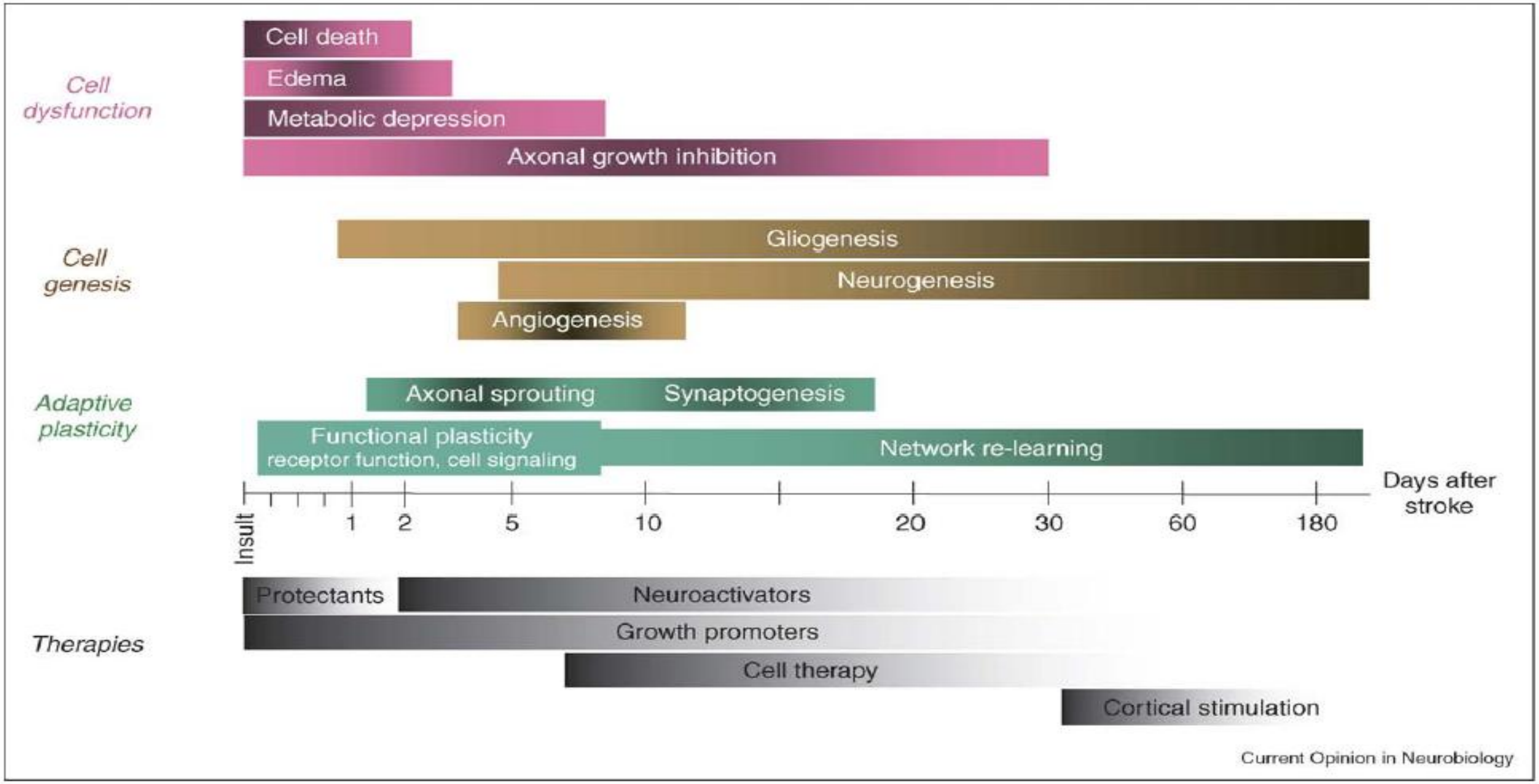
Mechanisms of Neuroplasticity (cont.)

- Desirable changes: achieve desired neural functions (movement, language, visual perception, etc)

- Undesirable changes: heightened reflex action (e.g., spasms), centrally maintained pain, etc.

Mechanisms of Neuroplasticity Following Stroke

Figure 1



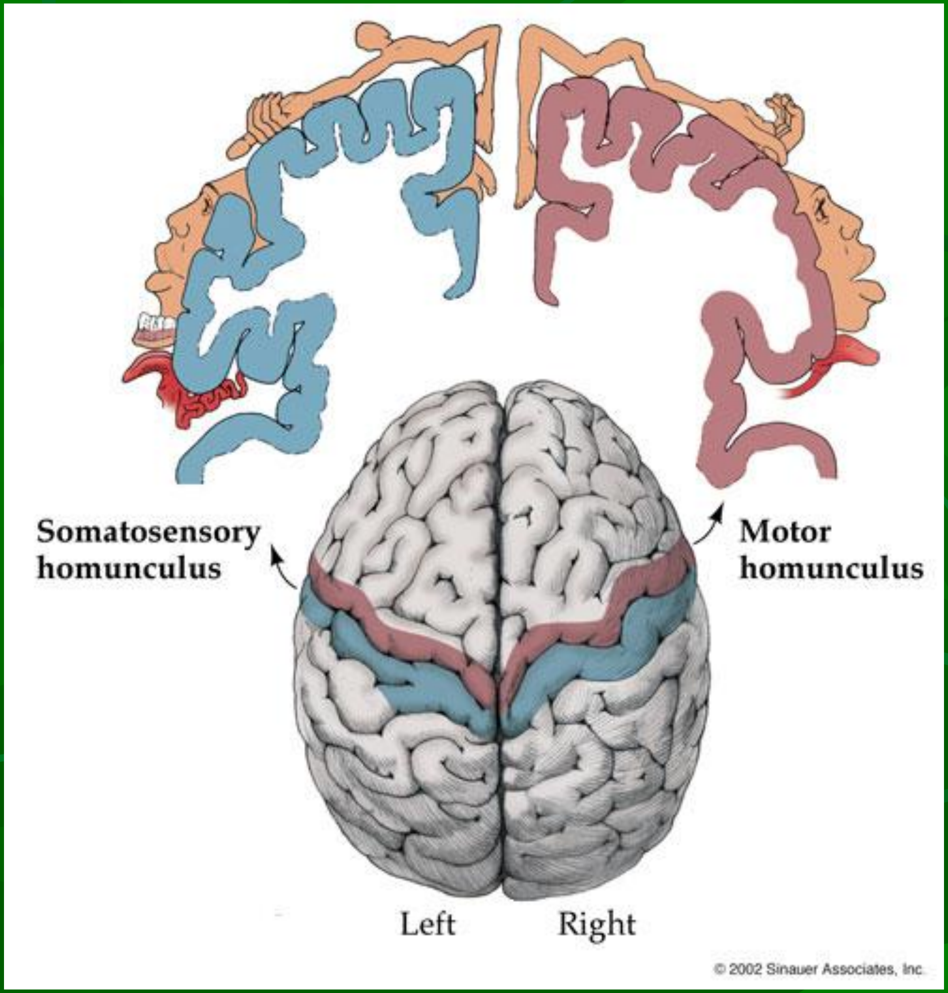
An overview of the activated parallel processes and therapeutic approaches following brain injury, specifically stroke. The temporal sequence of events is shown along a semi-logarithmic schematic timeline of 180 days after injury. Darker shading highlights the maximum intensity of the specific mechanism. Processes that are detrimental towards recovery are shown in pink. Processes of cell genesis are shown in brown, whereas those that underlie adaptive plasticity are shown in green. Prospective therapies that focus on neuroprotection and enhancement of regeneration and functional recovery are shown in gray.

Wieloch T, Nikolich K. Mechanisms of neural plasticity following brain injury. Curr Opin Neurobiol. 2006 Jun; 16(3):258–264

PT's Role In Improving Post-injury Plasticity

- Provide enriched environment
  - Functional recovery after stroke is enhanced by experience driven re-learning and, to a limited extent, by physical therapy.
  - This effect declines with time and is not effective if started 30 days after the stroke, and if initiated earlier than 2 days post-stroke it might even be detrimental
  - An enriched environment (EE) stimulates physical activity and sensory experience, but most importantly it provides a social component

Animal Studies: Cortical Re-Mapping



Blumenfeld H. Neuroanatomy Through Clinical Cases. Sunderland, MA: Sinauer Associates, Inc., 2002. [This image is in Figure 2.13]

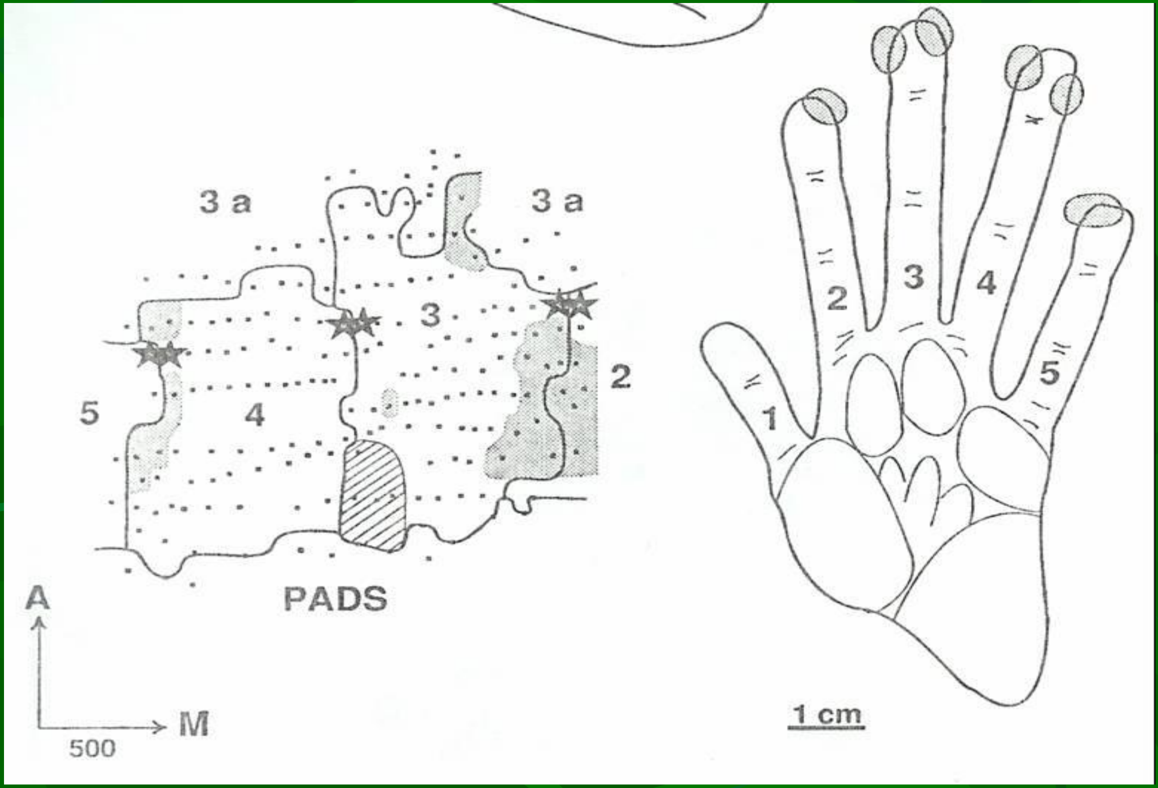
Study # 1

- Two of the monkey's fingers were stitched together (syndactyly surgery)
- The somatosensory cortex was mapped,
  - before the surgery
  - several months post-surgery
  - after syndactyly was released

Allard T, Clark, SA, Jenkins WM, Merzenich MM. Reorganization of somatosensory area 3b representations in adult owl monkeys after digital syndactyly. J Neurophysiol. 1991;66:1048-58.

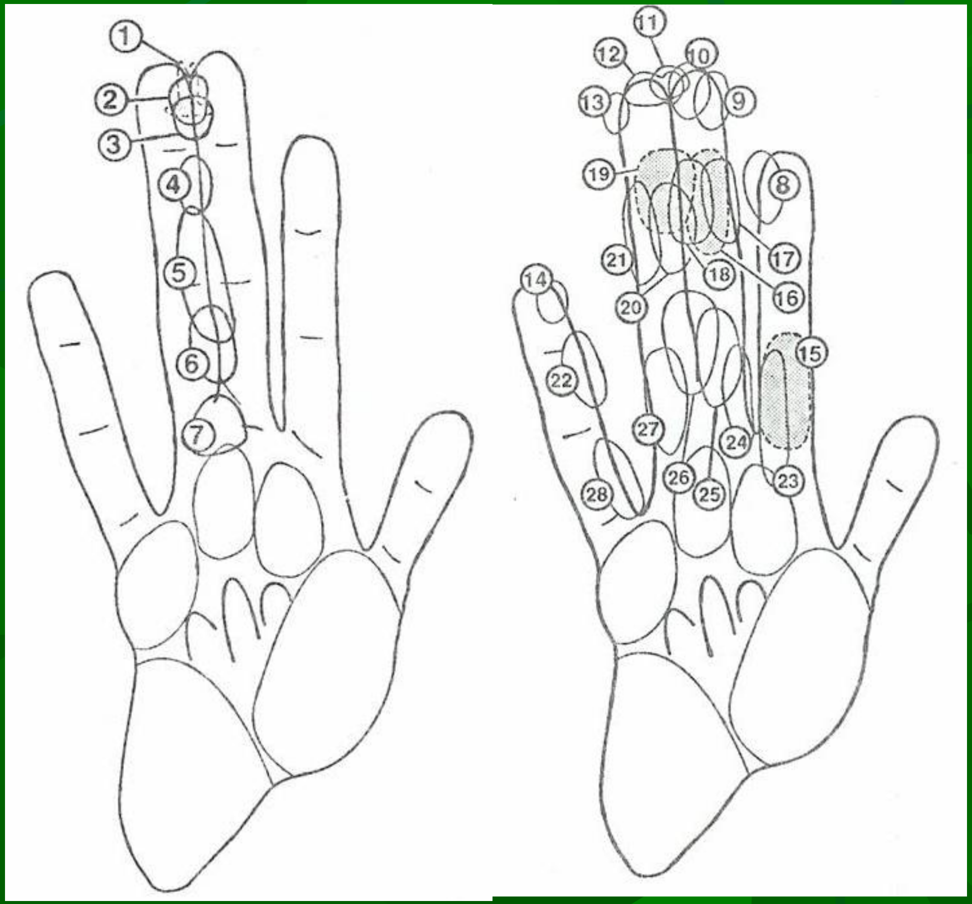
Study # 1 (cont.)

Normal map
before surgery

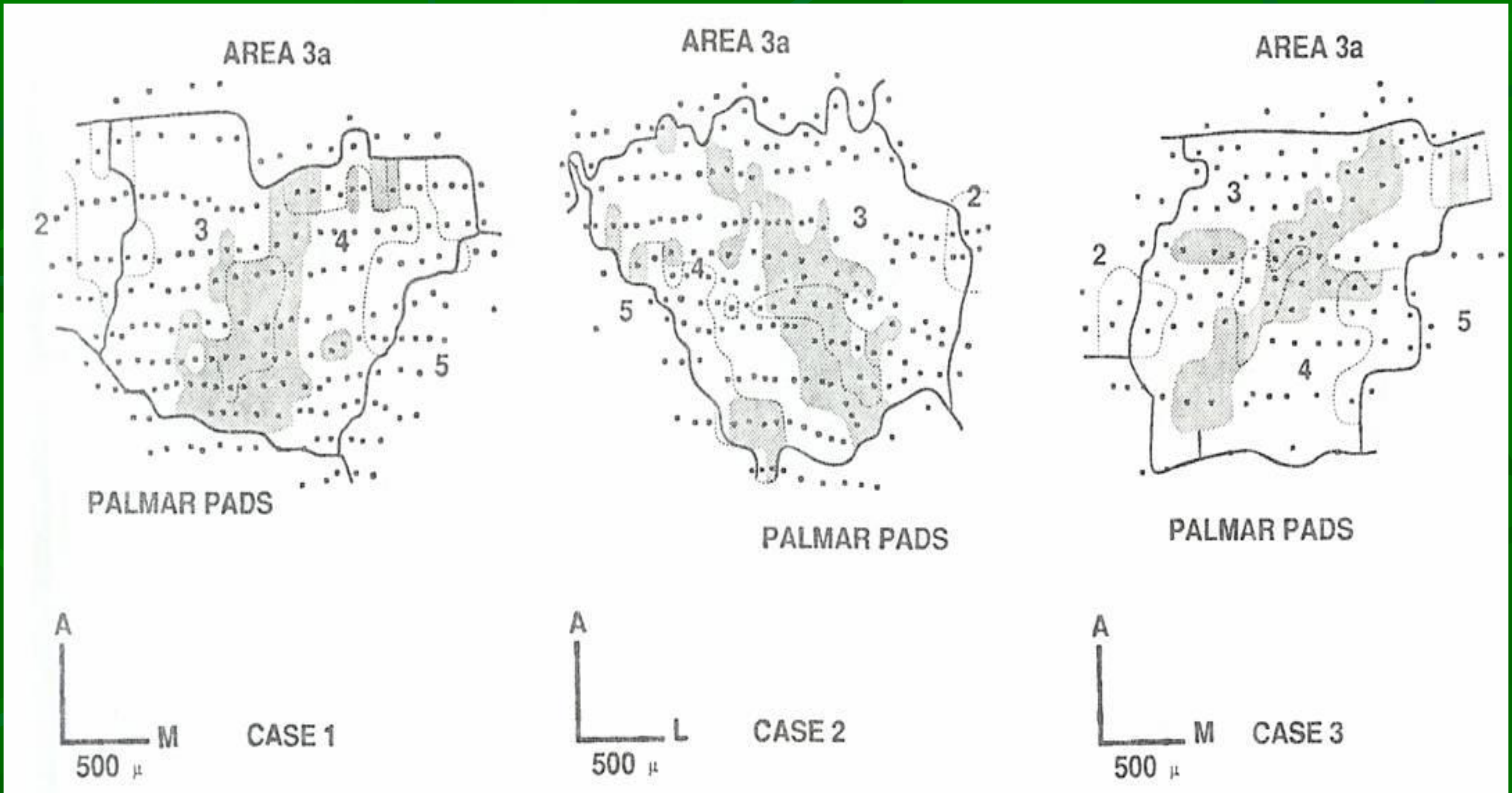


Study # 1 (cont.)

Several months post-surgery: receptive fields (RFs) developed that go across two fingers



Study # 1 (cont.)

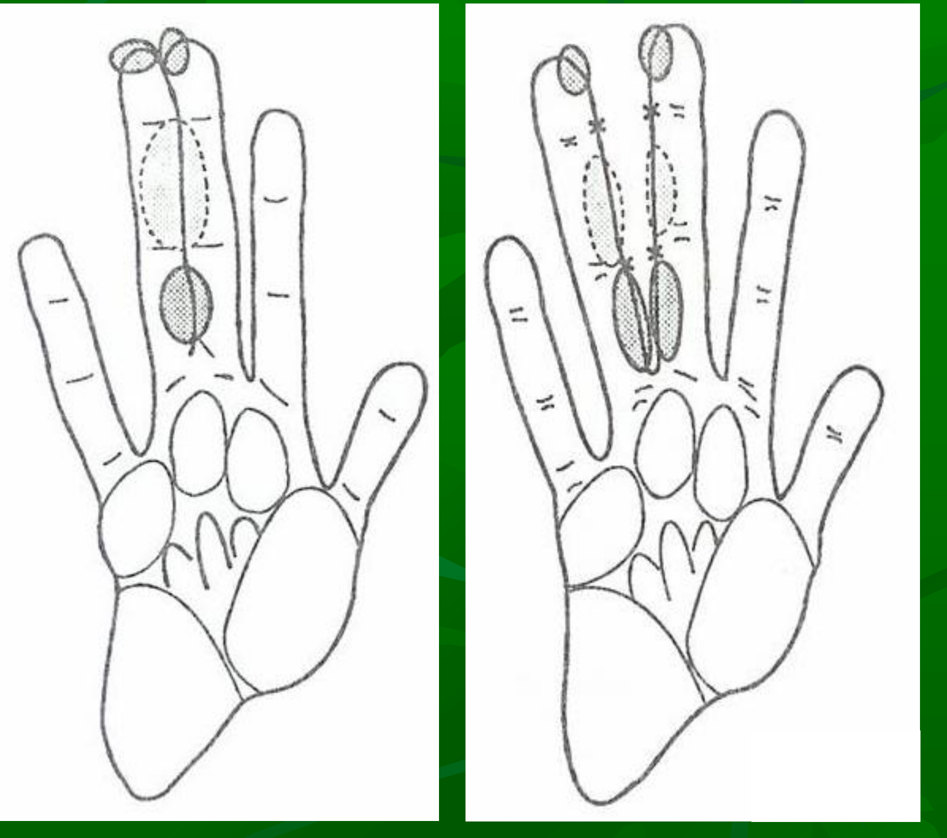


Post-surgery: shaded areas are regions that respond to touch of both digits within the syndactyly

Study # 1 (cont.)

After the digit syndactyly was released

- There were no longer any receptive fields that crossed two digits
- The cortical mapping reverted

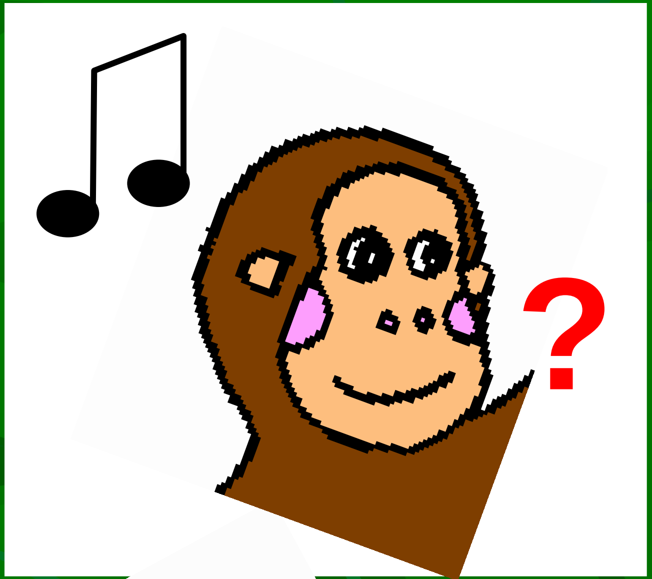


Study # 1 (cont.) *Implications*

- Primary somatosensory cortex map of the fingers is "plastic" and this plasticity can revert as the peripheral situation changes
- Neural representation depends on *functional* anatomy, rather than *structural* anatomy
  - Surgically attached digits develop receptive fields that go across digits

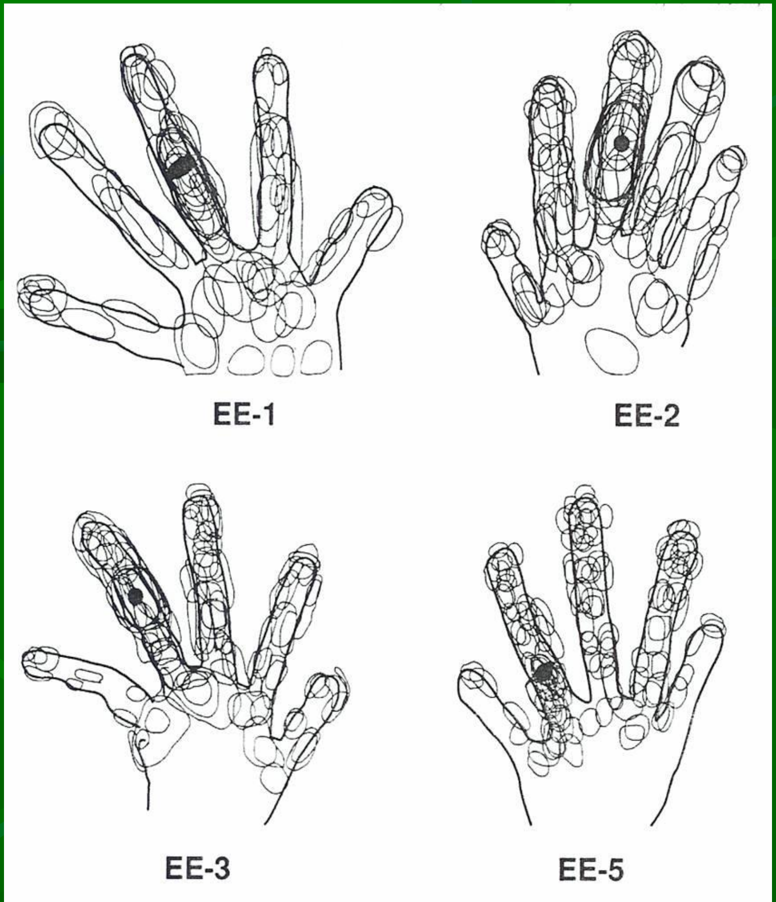
Study # 2

- One spot on one digit received the tactile flutter-vibration stimulus above a 20-Hz standard.
  - Some monkeys received reward for paying attention to hand stimulation
  - Others received reward for paying attention to auditory cue (passive stimulation controls)
- Dose of training
  - ~ 20 min/day
  - weeks to months

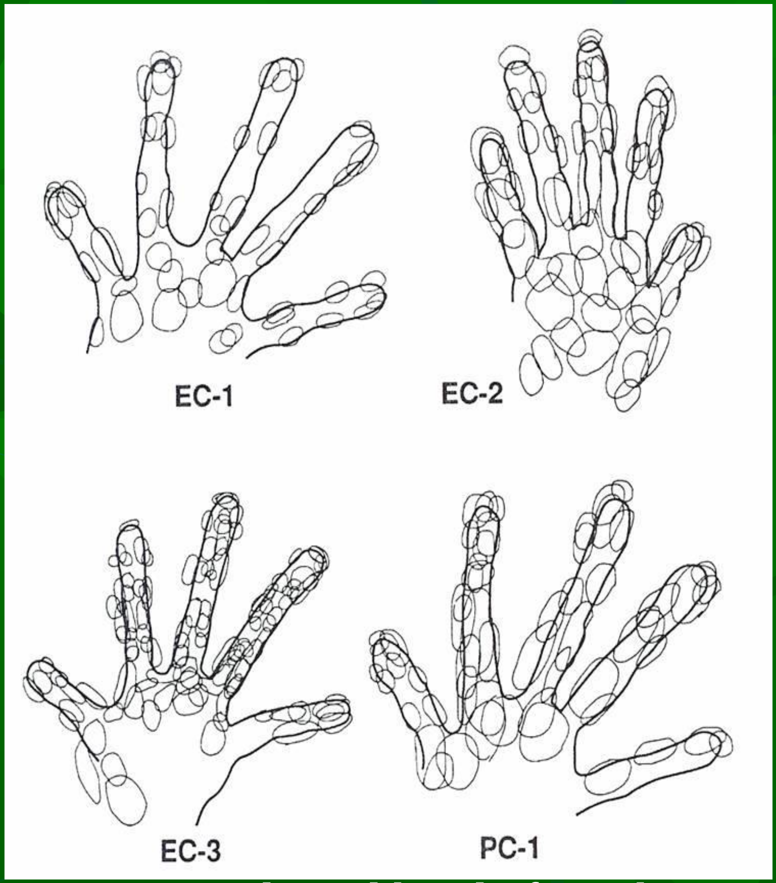


Recanzone GH, Merzenich MM, Jenkins WM, Grajski KA, Dinse HR. Topographic reorganization of the hand representation in cortical area 3b of owl monkeys trained in a frequency-discrimination task. J Neurophysiol. 1992;67:1031-56.

RFs Distribution in trained hands and control hands



RFs on the trained hands of monkeys received reward for paying attention to hand stimulation



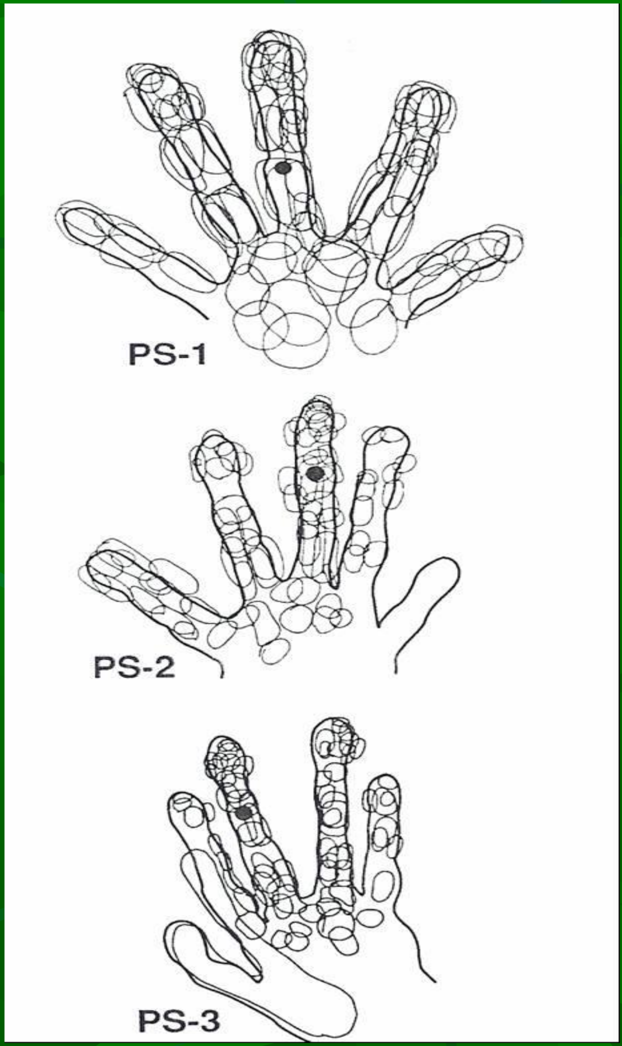
- EC = contralateral hand of monkeys received reward for paying attention to hand stimulation
- PC = contralateral hand of monkeys received reward for paying attention to auditory cue

Study # 2 (cont.)

- Monkeys that received reward for paying attention to hand stimulation
  - The larger RFs size
  - Substantially increased topographic complexity representing the stimulated hands
  - The largest RFs were centered in the zone where skin was stimulated
  - RFs sizes were also statistically significantly larger on at least one adjacent, untrained digit

Study # 2 (cont.)

- Monkeys trained with auditory cue
  - Only modest increases in topographic complexity
  - No effects on RFs size



PS = ipsilateral hand of monkeys trained with auditory cue

Study # 2 (cont.) *Implication*

- Changes in neural representation occur if the individual pays more attention to the stimuli

Study # 3

- Two monkeys were trained in a highly stereotyped arm motion to retrieve food pellets
  - 20 weeks
  - 3-400 trials per day
  - Sensory area was mapped before and after the training

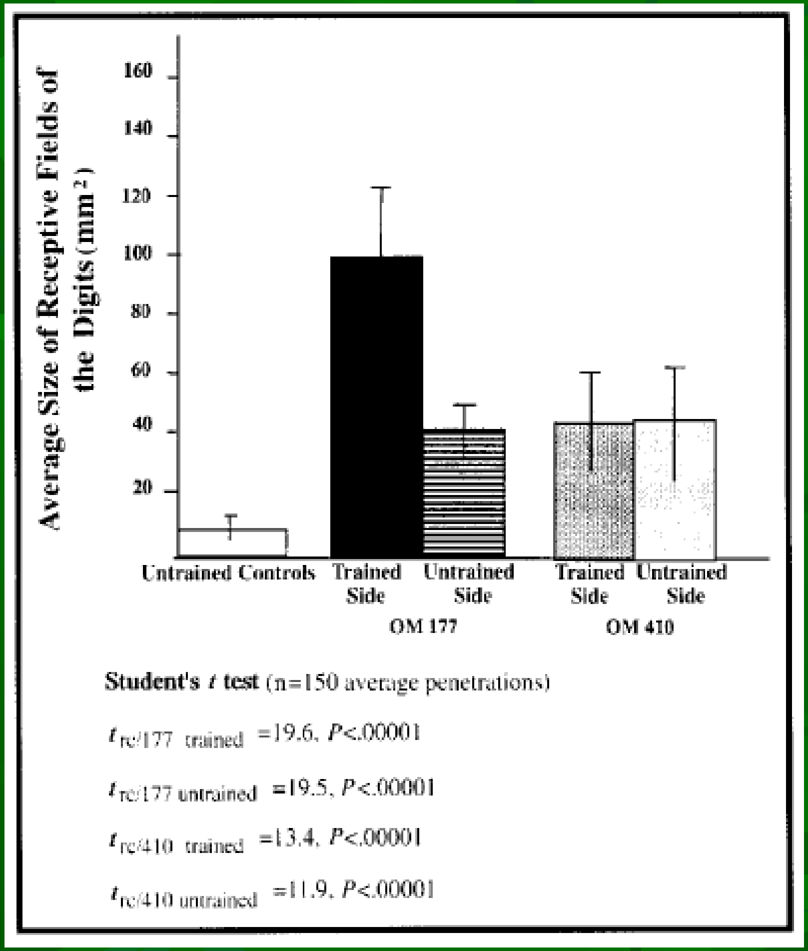
Byl NN, Merzenich MM, Cheung S, Bedenbaugh P, Nagarajan SS, Jenkins WM. A primate model for studying focal dystonia and repetitive strain injury: effects on the primary somatosensory cortex. Phys Ther. 1997;77:269-84.

Study # 3 (cont.)

Both monkeys showed decreased performance after 4-5 weeks, and changed the handgrip to be able to continue.

One monkey also changed the shoulder & elbow movement, and refused to train more than 30 minutes at a time.

The receptive field size increased in association with training.



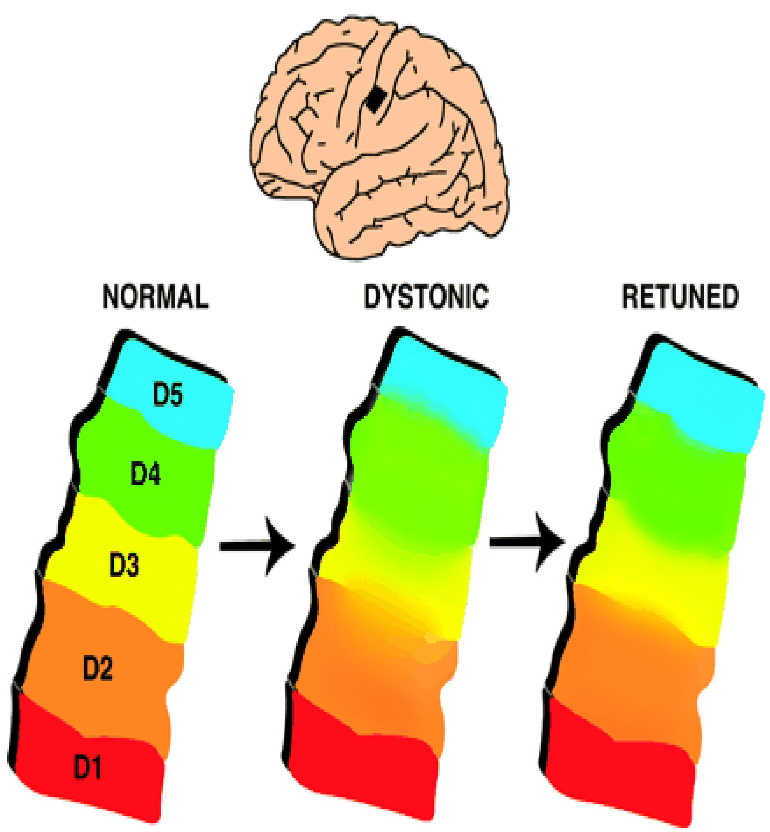
Study # 3 (cont.) *Implication*

- Some of dysfunction associated with repetitive use may be related to CNS changes rather than peripheral soft tissue changes

What is the suggested rehabilitation for this condition?

Human study: varying neural maps

Hypothetical alterations in the topography of the hand representation in somatosensory cortex in focal dystonia associated with repetitive use



Proposed "retuning" therapy:

Immobilize digits that exhibit abnormal movements and practice movements of other digits

Image from: Nudo RJ. Retuning the misfiring brain. Proc Natl Acad Sci USA 2003; 100: 7425-7.

Human study (cont.)

Objective: To evaluate the long-term effectiveness of sensory motor retuning (SMR) for focal hand dystonia in 11 professional musicians in general community in Germany.

Intervention: Immobilization by splints of the focal dystonic finger in turn the other fingers involved in the abnormal movement pattern (*main compensatory finger).* This finger carried out repetitive exercises in coordination with 1 or more of the other fingers for 11⁄2 to 21⁄2 hours a day for 8 consecutive days under therapist supervision. The subjects then were instructed to continue practice for 1 hour daily for 1 year.

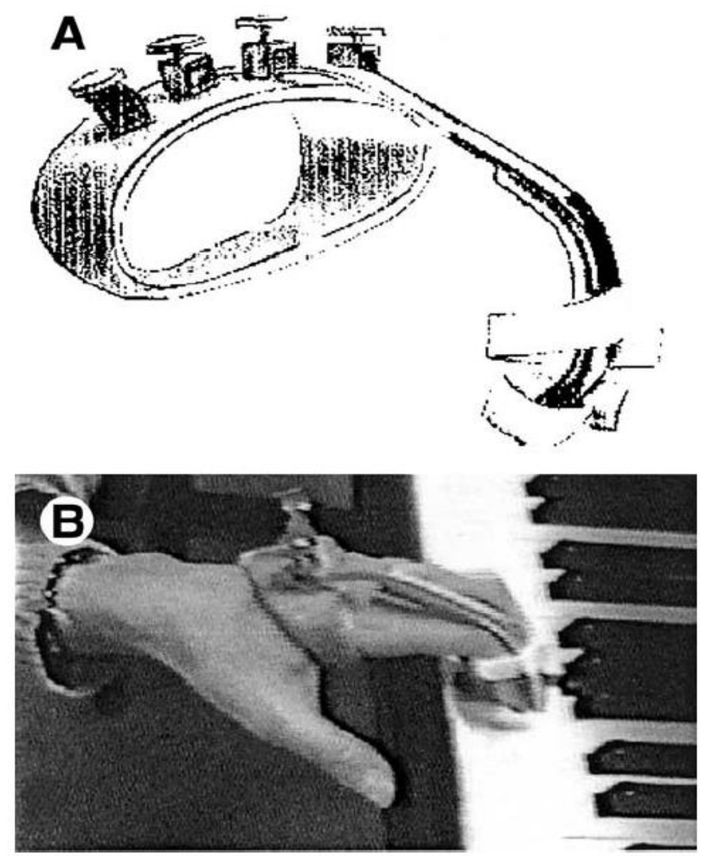


Fig 1. Splint device used to immobilize fingers of the dystonic hand. (A) The device was tailored to the dimensions of each individual's hand and the requirements of the instrument he/she played. (B) Hand in splint with D2 immobilized.

Candia V, Schäfer T, Taub E, Rau H, Altenmüller E, Rockstroh B, Elbert T. Sensory motor retuning: a behavioral treatment for focal hand dystonia of pianists and guitarists. Arch Phys Med Rehabil 2002; 83: 1342-8.

Human study (cont.)

- **Results:**

The 3 wind players (adventitious placebo controls) did not improve substantially. However, each pianist and guitarist showed marked and significant improvement in spontaneous repertoire performance without the splint.

Implications For Rehabilitation

General Comments

- Neurons that fire together would wire together (Hebb 1949)
- “As therapists, we have to enable [the patient] to experience the normal sensations of functional movements which [he/she] has lost... (Bobath 1978)
- Experience is hugely important in shaping our neural representations -- reinforcing some pathways and not others
- Overall life experience and habitual patterns have a strong, long-lasting effect
- What the patient does outside of rehabilitation is important too
- Injury destabilizes some representations and creates a situation in which the brain may be more plastic for a while, So early intervention to provide “experience” is important.
- But also, neuroplasticity is a lifelong phenomenon, so people can improve for a long time post-injury

How to provide “Experience”

- Neuromotor control improves when the neural circuits experience active movements and the sensations that arise from active movement
  - e.g., if you want someone to improve at using sensory input to guide motor output, they need
    - the experience of all that sensory input
    - the chance to attempt that motor output
    - the chance to learn from errors within safety limits
- Neural changes related to sensorimotor status are greatest if the person is active and/or paying attention

How to provide "Experience" (cont.)

- Experiences provided in rehabilitation have to be reasonably specific:
  - e.g. strength training in lower extremities is unlikely to improve walking unless opportunities to practice walking coordination are also provided

- Create opportunities for neural experience of movement
  - patients need somatosensory experience of movement, visual, vestibular and emotional experience, and the experience in planning and executing movement.

Implicit Motor Learning

A large portion of the rehabilitation experience after stroke relies on implicit learning

Why?

Learn And Memory: Explicitly Vs. Implicitly

- Two main categories -- explicit and implicit processes.
- Explicit learning
  - facts and ideas
  - assessed directly by testing knowledge of facts and events
  - explicit memories form in as little as one exposure to new information
- Implicit learning
  - habits and behaviors
  - only inferred from observation of performance by changes in skilled behavior
  - implicit memories form very slowly, accumulating with + + practice.
  - E.g., bicycle riding -- improved performance is manifested by fewer falls

Body LA, Winstein CJ. Explicit information interferes with implicit motor learning of both continuous and discrete movement tasks after stroke. Journal of Neurologic Physical Therapy. Jun 2006;30(2):46-59.

Implicit and Explicit Learning: Do they Interact?

- The explicit and implicit learning and memory systems are neurobiological isolation from one another. This dissociation has been demonstrated both neuroanatomically and functionally.
- The explicit system is mediated by the hippocampus and adjacent medial temporal lobe structures, which owing to their focal nature may be completely destroyed by certain kinds of damage or disease.
- The implicit system is highly distributed making it nearly impossible to completely disrupt.

Study # 1: Explicit Instruction (EI) Interferes with Implicit Motor Learning

- Learning new, and re-learning old, motor skills consumes the largest portion of time in the rehabilitation process after stroke.
- In order to facilitate implicit motor skill learning, physiotherapists spend considerable time providing explicit instructions focused on 'how to' perform movement tasks.
- However, evidence shows this type of information does not aid and may even hinder implicit learning after stroke.

Body LA, Winstein CJ. Explicit information interferes with implicit motor learning of both continuous and discrete movement tasks after stroke. Journal of Neurologic Physical Therapy. Jun 2006;30(2):46-59.

Study # 1 (cont.)

- **Participants:** 10 individuals with stroke in the sensorimotor cortical areas (SMC), 10 with stroke in the basal ganglia (BG), and 10 age-matched healthy controls (HC)

- **Intervention**: each completed 3 days of practice of both a discrete implicit motor task (the serial reaction time task) and a continuous motor task (the continuous tracking task); all returned on a fourth day for retention tests. By random designation, participants were divided into either the explicit information (EI) or no explicit information (No-EI) groups.

Study # 1 (cont.)

Table 2. Explicit Information and Knowledge Testing Conditions by Explicit Information (EI) Group and Day

Group		Day 1	Day 2	Day 3 Prepractice	Day 3 Postpractice	Day 4 Retention Test
EI	*Information condition*	"Respond as fast as possible"	Partial explicit awareness: "Sequence exists"	Full explicit information: verbal instructions, study session, and pretest		"Respond as fast as possible"
	Explicit knowledge test	Subjective and recognition	Recognition	Prepractice test of recognition	Postpractice test of recognition	None
No-EI	*Information condition*	"Respond as fast as possible"	"Respond as fast as possible"	"Respond as fast as possible"		"Respond as fast as possible"
	Explicit knowledge test	None	None	None	None	Subjective and recognition

Study # 1 (cont.)

- **Results:** the response to explicit information after stroke was uniformly negative ***regardless of task or lesion location***; both stroke groups demonstrated an interference effect of explicit information while the healthy control group did not.

- **Implications for rehabilitation**
  - Explicit information delivered before task practice may not be as useful for learning as ***discovering the solution to the motor task with practice alone,*** and this is regardless of the type of task being learned.

Study # 2: Does Gaining Explicit Awareness Of A Sequence During Practice Facilitate Implicit Learning?

- **Participants:** 9 healthy participants (mean age, 27.3 years)

- **Tasks:** All participants engaged in 10 blocks of 10 trials of a 30-second continuous tracking task over 2 days of acquisition practice. Participants returned on a third day for retention testing. The pattern of the targets movement was constructed using a method modified from Wulf and Schmidt. During training, participants were exposed to the repeated epoch 100 times (EI) and also to 100 novel (No-EI), randomly generated epochs.

- **Results:** all participants reduced tracking error with practice. However, the implicit group was initially more variable in their responses, whereas acquired explicit knowledge resulted in more variability late in practice. Interestingly, higher variability during practice did not affect learning.

Vidoni ED, Boyd LA. Achieving Enlightenment: What Do We Know About the Implicit Learning System and Its Interaction With Explicit Knowledge? Journal of Neurologic Physical Therapy. 2007; 31(3):145-154

Study # 2 (cont.)

Implications for rehabilitation

- Because the impact of EI depends on multiple issues including the presence or absence of a lesion, specific lesion location, and implicit task characteristics, it is difficult to form one conclusion.

- The study suggest that in the context of rehabilitation, the delivery (or not) of EI is simply another variable that PT may manipulate to facilitate motor learning. It appears that during motor skill practice, learners can discover the correct solution to a movement problem using either their implicit, explicit, or a combination of these two memory systems; each strategy may lead to motor skill learning.

References

Allard T, Clark, SA, Jenkins WM, Merzenich MM. Reorganization of somatosensory area 3b representations in adult owl monkeys after digital syndactyly. J Neurophysiol. 1991;66:1048-58

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What Do You Think?

Questions?