Introduction to Rehabilitation Robotics

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Contents

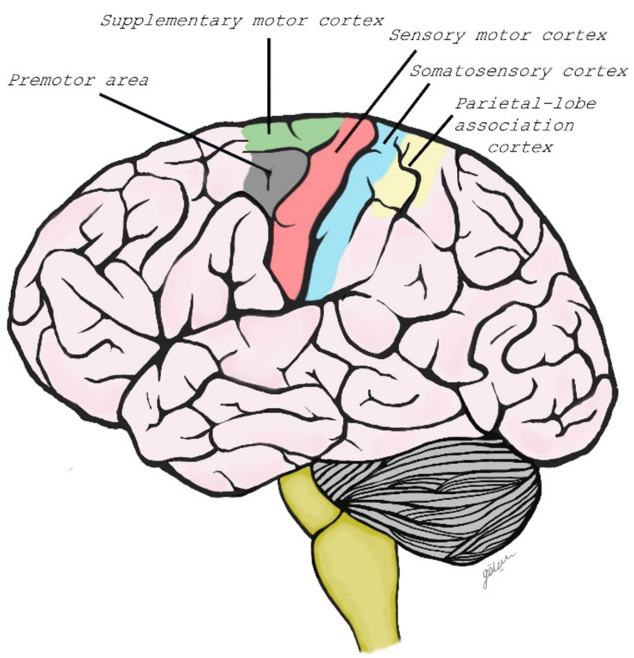
- Neural principles
- Key Factors for recovery
- Technologies for rehabilitation
- History of rehabilitation robotics

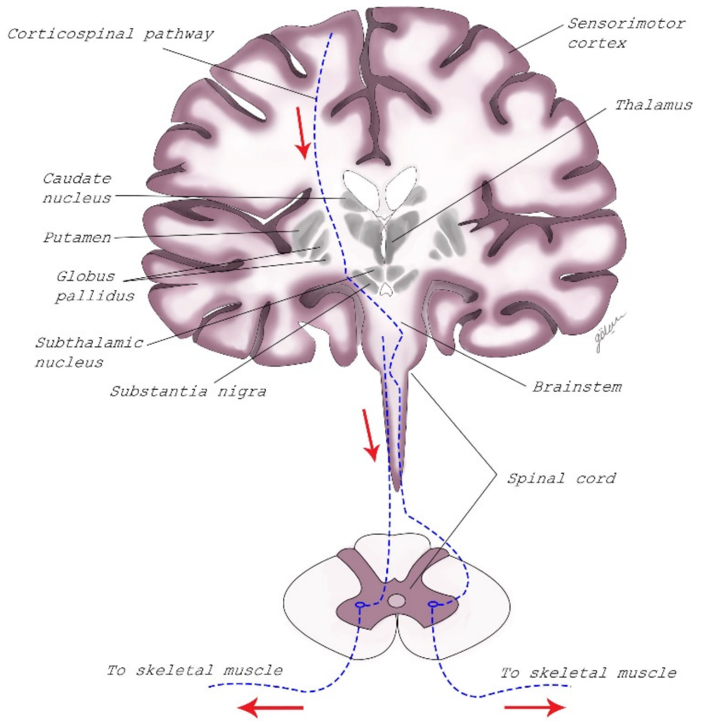
Introduction to Rehabilitation Robotics

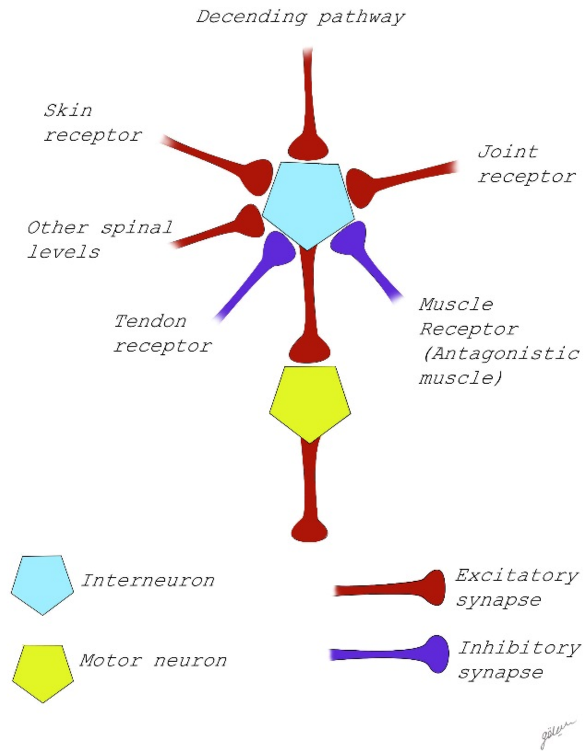
NEURAL PRINCIPLES

Neurological Principles

- Cells in the brain called neurons control our movement by sending signals to cells in the spinal cord which in turn connect with the muscles.

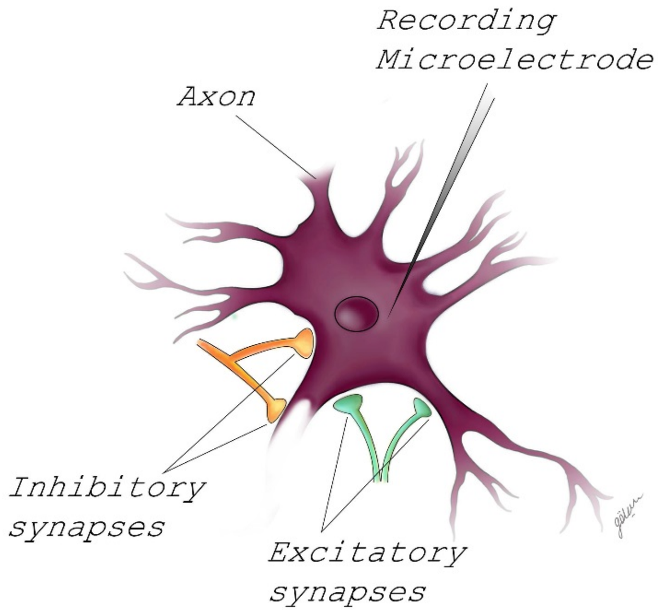


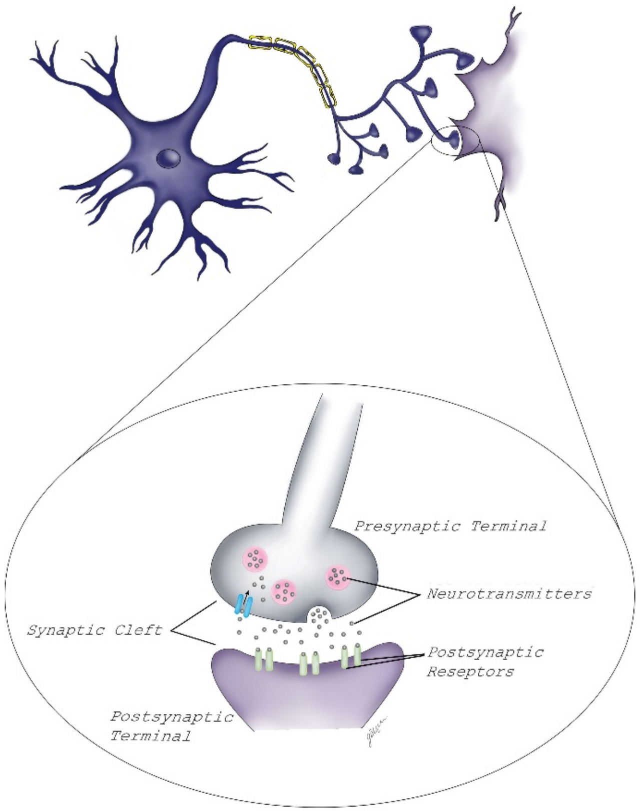


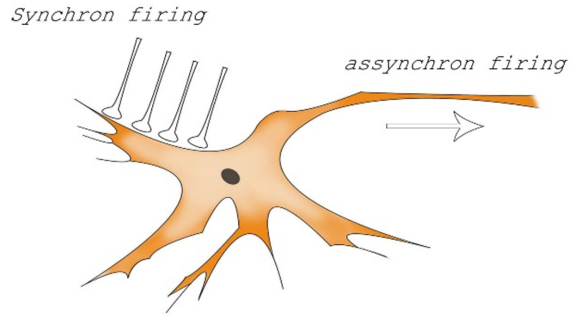


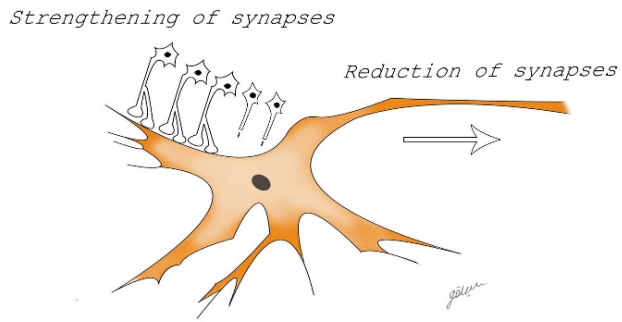
Neural Transmission

- The movement signals are relayed from one neuron to another via synapses. The connection strength of synapses is variable and forms the basis for learning and memory.





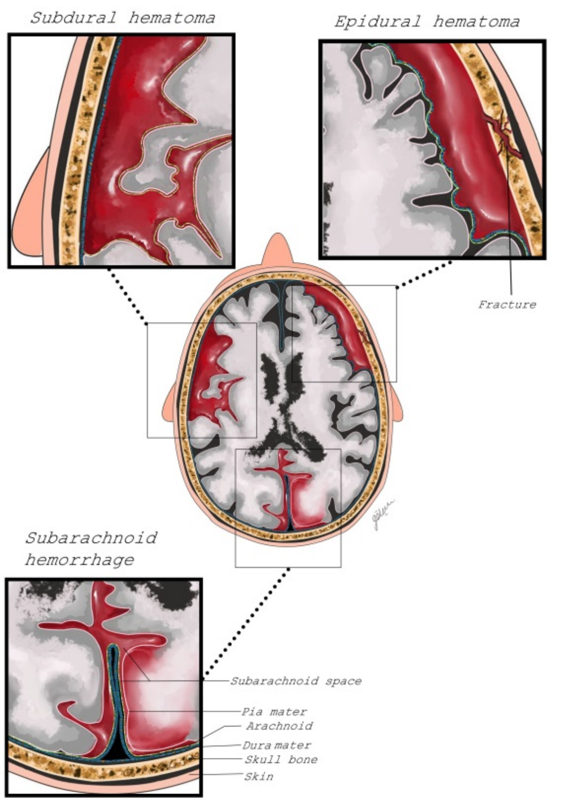




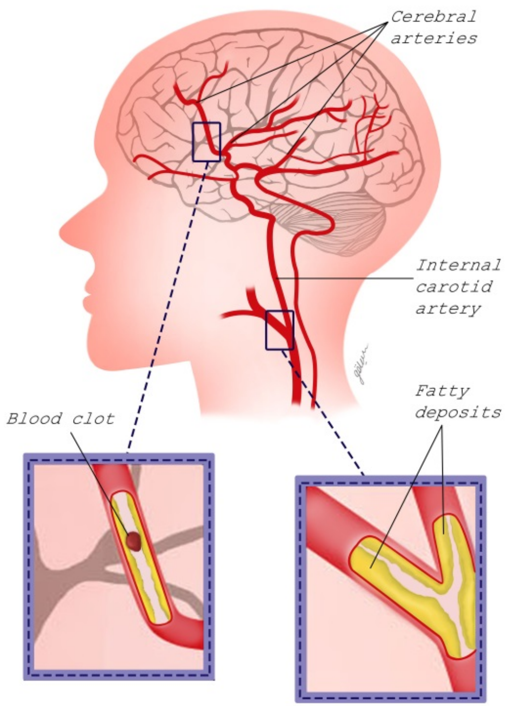
Central Nervous System Injuries

- Our ability to move around can be impaired by damaging neurons in the brain (stroke, TBI) or interrupting the signal pathway via the spinal cord to the muscles (SCI).

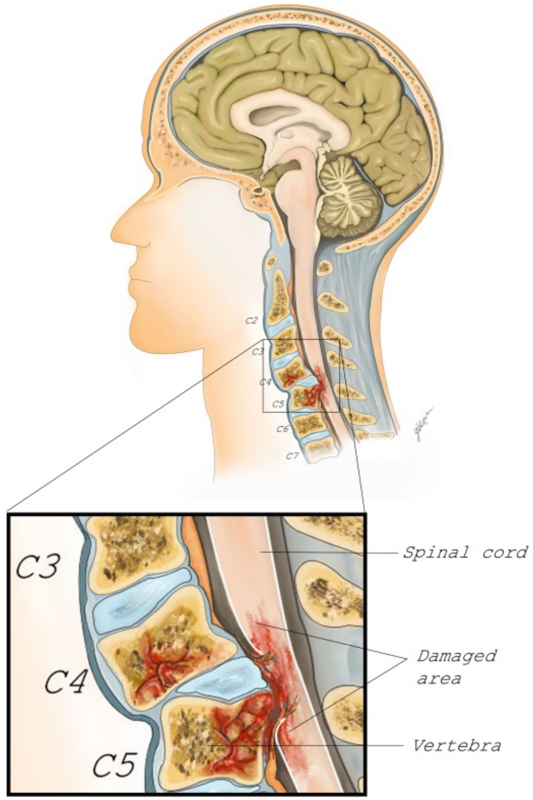
Traumatic Brain Injury



Stroke



Spinal Cord Injury



Motor Impairments after Stroke

- Impairments have impacts on activity and participation, independence and quality of life.

49% balance

44% arm movement

52% hand movement

44% leg movement

54% walking

* NSA survey: http://www.stroke.org/site/DocServer/StrokePerceptions_FinalSurveyResults_2006.pdf

31% require assistance

20% need help walking

16% institutionalized

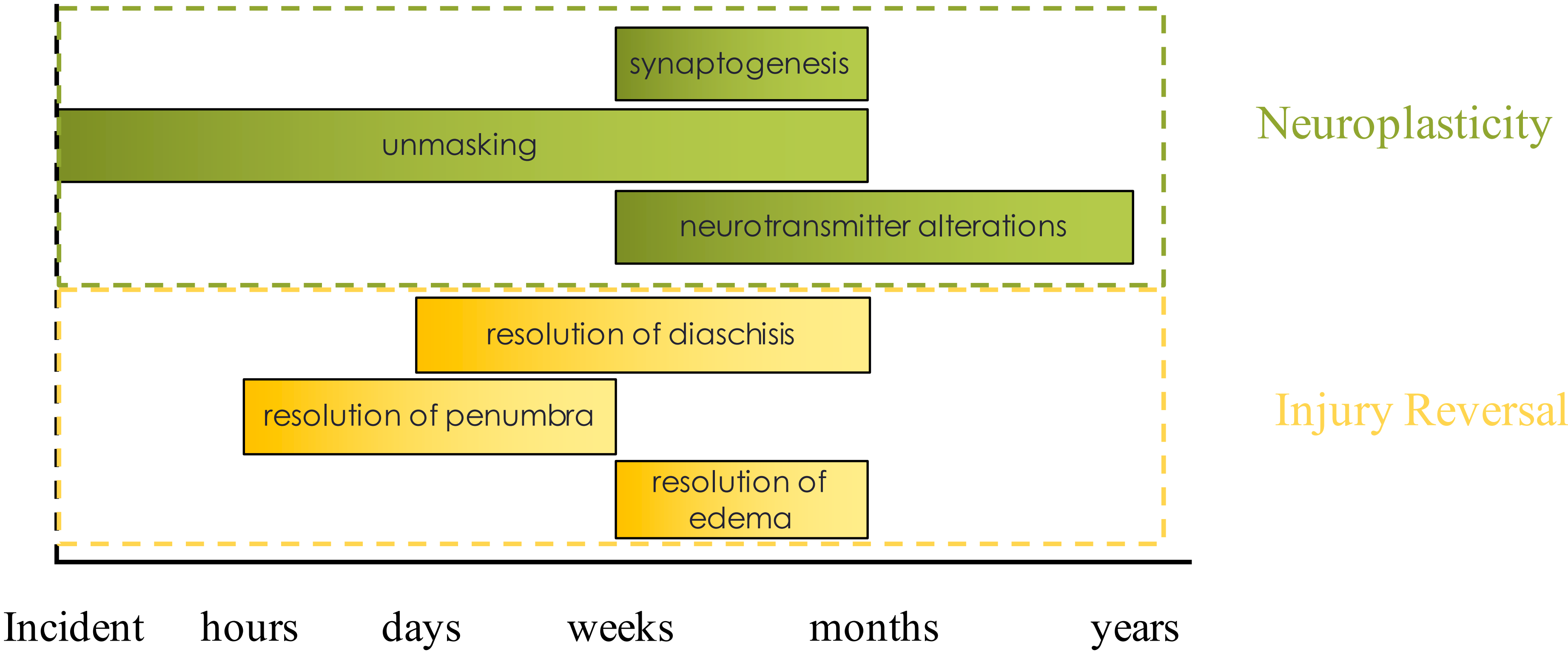
71% vocationally impaired after 7 years

34% unemployed at <65 years

** NSA stroke guide: http://surgeonwriter.com/wp-content/uploads/2014/05/NSA-Stroke-Guide.pdf

Mechanisms of Recovery

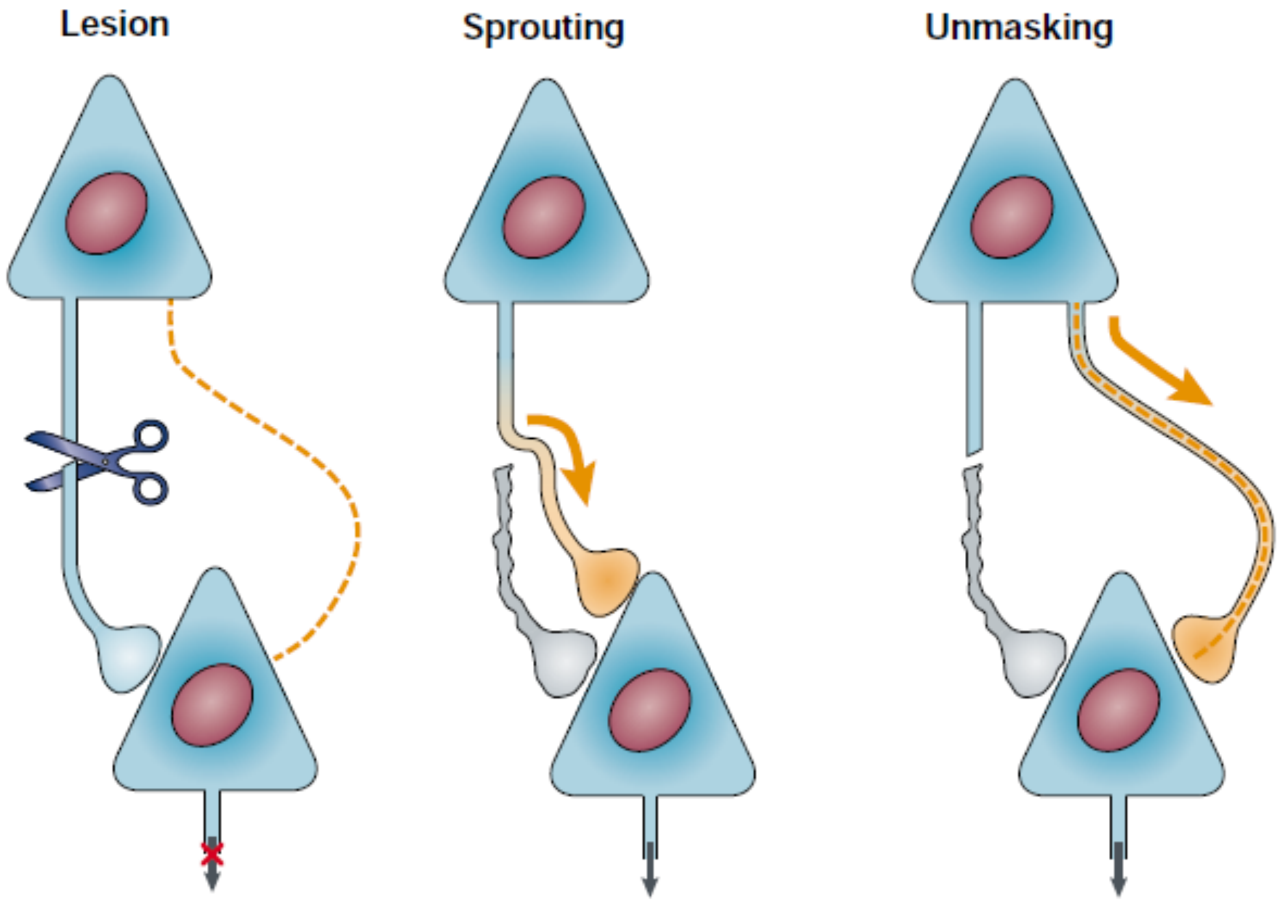
- Recovery is a combination of reversal of injury related factors (edema, diaschisis) and neuroplasticity.



Neuroplasticity

- The ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function and connections.
  - Harnessing neuroplasticity for clinical applications, Cramer et al. 2011

Neuroplasticity is the modification of the nervous system on a cellular and behavioral level. It is triggered by injury or activity/training



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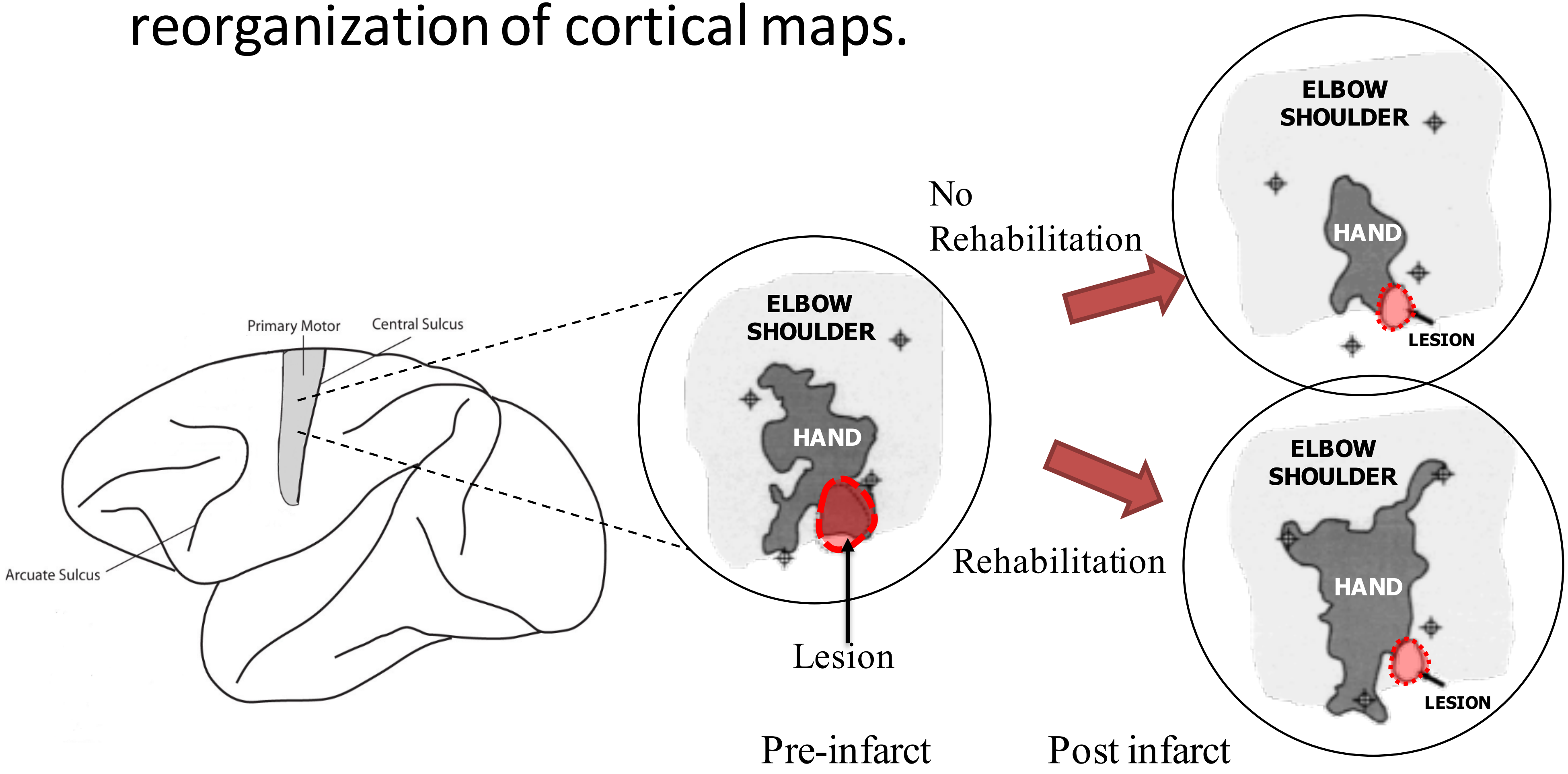
Activity-Induced Neuroplasticity

- Active training enhances neuroplasticity and results in reorganization of cortical maps.



Lessons Learned

- We move by sending movement commands from neurons in our brain to our muscles.
- The signals are transmitted from neuron to neuron via synapses which can adjust their relay strength allowing us to learn and improve movements.
- Damage to the neurons in the brain or interruption of the signal pathway result in motor impairments which negatively impact our daily life.
- Recovery happens to some part spontaneously by resolving injury-related factors but also due to neuroplastic processes.
- Repeated activity and training triggers neuroplasticity which modifies the central nervous system to recover functionality.

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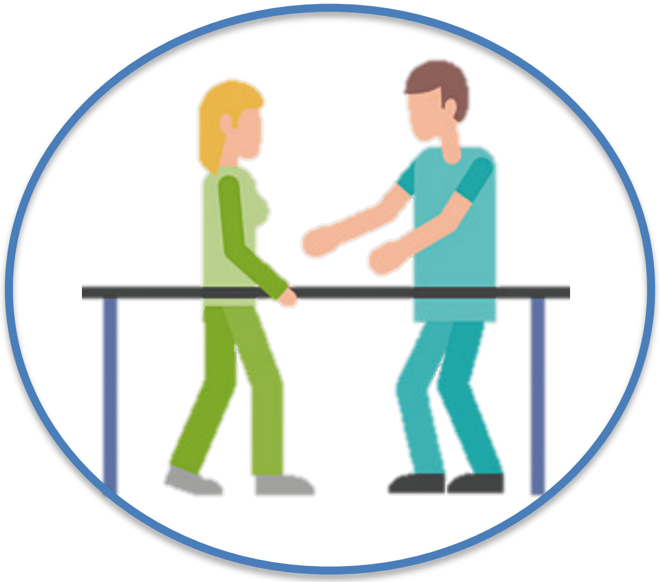
KEY FACTORS FOR RECOVERY

Activity-Induced Neuroplasticity

- Neuroplasticity and learning can be driven by several key factors taken from motor learning theory

Intensity

- Repetitions
- Duration
- Distribution / Frequency
- Effort
- Difficulty



Manner

- Task segmentation
- Specificity / Functionality
- Variability
- Initiation
- Shaping

Psychological Factors

- Motivation

Information

- Instructions
- Feedback

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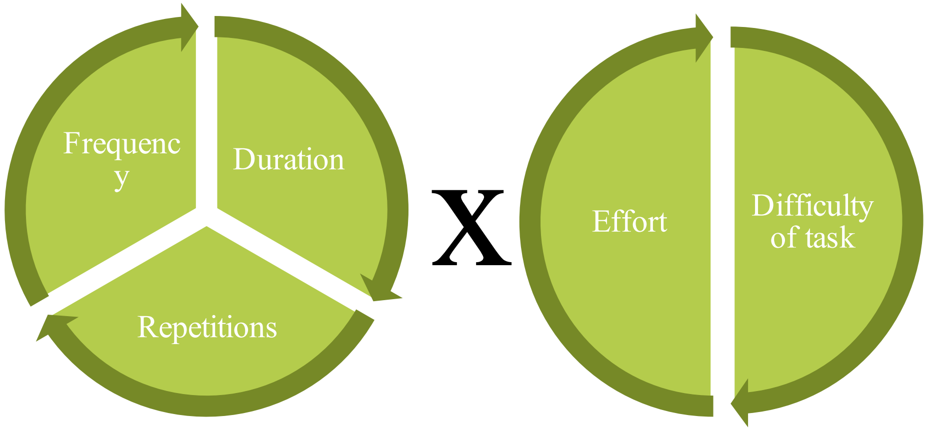
Intensity: Overview

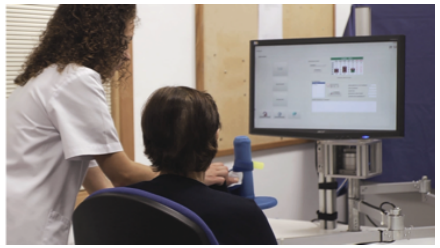
- Therapy needs to be intensive, active and challenging for optimal recovery to take place

Intensity	
• Repetitions	--- *Repeated performance of a movement/task*
• Duration	--- *Time of a single therapy session or entire therapy*
• Distribution / Frequency	--- *Amount of rests between repetitions or therapy sessions*
• Effort	--- *Active participation of the patient (physical and mental)*
• Difficulty	--- *Level of challenge during therapy sessions*

Intensity =



Robots



Intensity

- Repetitions
  - More repetitions lead to improved outcomes. A minimal amount of repetitions might be required for recovery to take place
  - How much is enough?
- Duration
  - In general, more therapy hours results in better outcomes. Due to cost and limited manpower current therapies provide only low therapy times.
- Distribution and Frequency
  - There is weak evidence that distributed practice might be better for a safe and effective therapy than massed practice (no rest).

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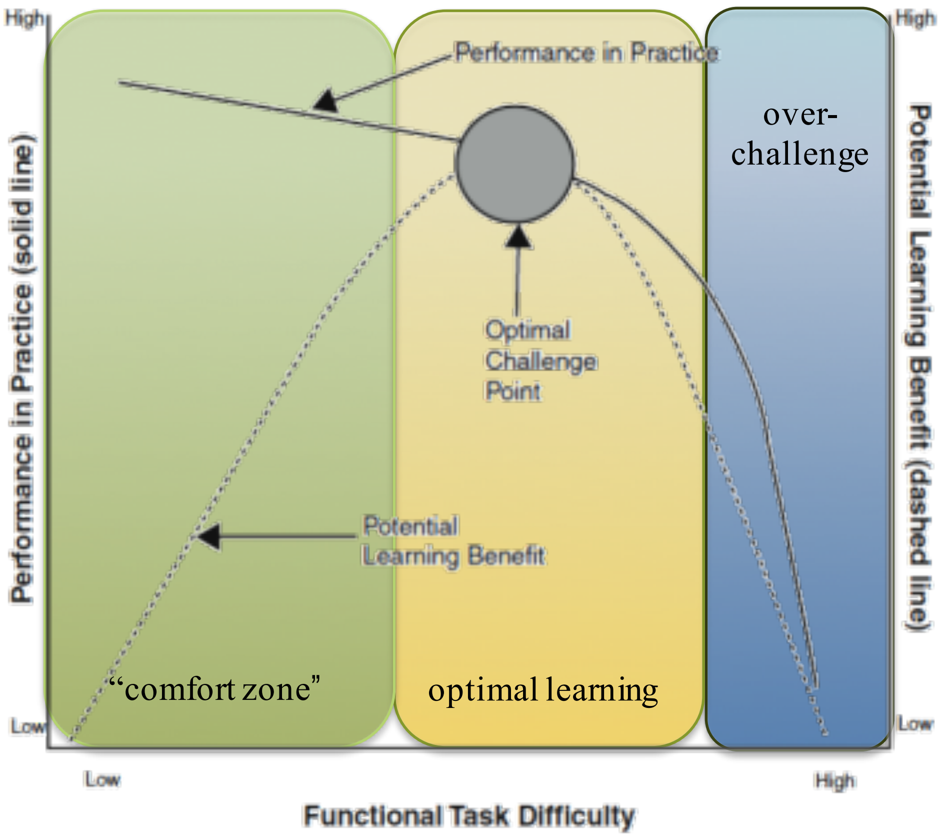
Intensity



- Effort
  - Patients should participate as actively as possible and be cognitively challenged without being overwhelmed.
- Difficulty
  - Training should be adjusted for each patient for an optimal challenge. The optimal learning difficulty is not identical with the difficulty under which performance is greatest.

Manner: Overview

- Therapy should start early, focus on practice of tasks used in daily life and include a high amount of variability.

Manner	
Task segmentation	*Training a simplified version or only a part of a movement*
Specificity / Functionality	*Training of specific, essential tasks used in daily life*
Variability	*Amount of diversity or randomness contained in a task performance*
Initiation	*Timing of the therapy start*
Shaping	*Continuously adjustment of task difficulty combined with reinforceme*

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Manner

- Task segmentation
  - Tasks should only be broken down into parts if composed of distinct subparts or if the whole task proves to be too difficult to learn.
  - Types
    - *Fractionalization*: Breaking bilateral tasks into two unilateral parts.
    - *Progressive part practice*: Separate task into several subparts.
    - *Simplification*: Reducing complexity of the task or parts of it.
- Specificity / Functionality
  - Patients should focus practice on activities essential in daily-life in a setting which is as realistic as possible.
  - Task oriented training improves function and changes cortical activation

Manner

- Variability
  - In general, practicing a task with variable setting or in a random order improves learning and the ability to generalize
- Initiation
  - Current evidence suggests to start rehabilitation early after the incident.
  - There is evidence that early rehabilitation leads to better outcomes but no optimal time ranges have been established. Recovery decreases the longer therapy is delayed.
  - Some animal studies have shown worse outcomes if therapy started with high intensity right after a stroke

Manner

- Shaping
  - Shaping or adapted task practice is defined as a method in which a motor or behavioral objective is approached in small steps by successive approximations or by making the task more difficult in accordance with the patient's motoric capabilities."
  - Shaping is important to avoid frustration but also to avoid boredom
  - Adjusting task challenge in small steps while encouraging (reinforcing) improvement is an effective practice method.

Wolf et al. 2002

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Psychological Factors: Overview

Psychological Factors

- Motivation --- *Motivation to practice and perform tasks*

- Motivation is very important for adhering to intensive therapy and leads to improved training outcomes.
- Motivation has a strong influence on successful rehabilitation. Low motivation negatively affects patients, rehabilitation staff and family members.
- There exist a variety of ways to increase motivation can be increased which benefit learning.
  - Making the task seem important
  - Effect of Goal-setting
  - Benefits of positive feedback

Information: Overview

- Information can critically influence learning in a positive or negative way. Giving too much and redundant information should be generally avoided.

Information

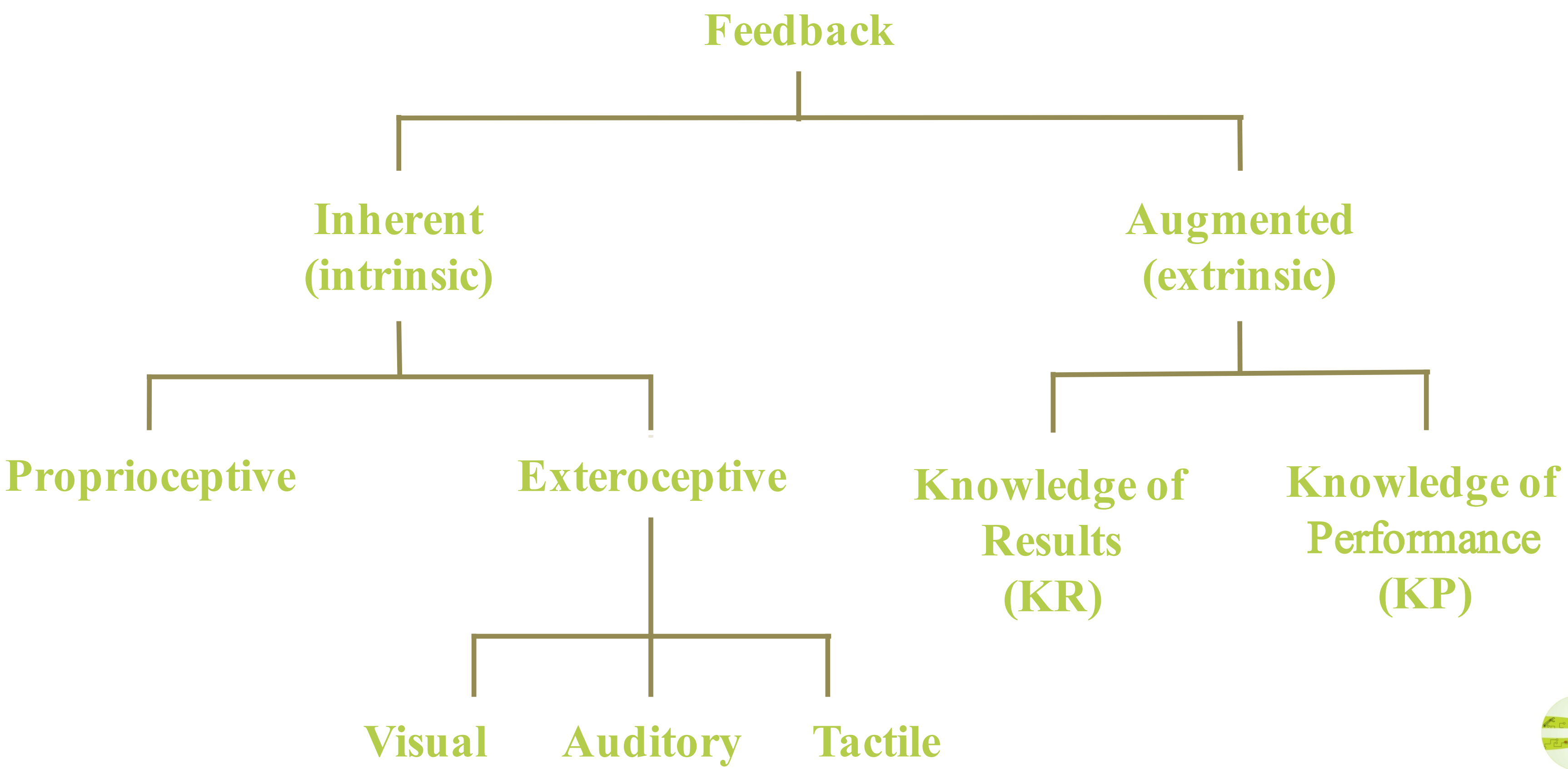
- Instructions — *Information given before practice to facilitate correct performance*
- Feedback — *Information signaling outcome and correctness of performance*

Information

- Instructions
  - Instructions can assist with learning if used in the right way (sparsely intermixed with practice).
  - Effect of instructions:
    - The way instructions change a subjects focus can have detrimental effects on performance and learning
  - Usage of instructions
    - Only convey general ideas which are essential for first trials. Add more instructions progressively due to limited amount of instructions that can be remembered
  - Optimal schedule
    - Interspersing active practice with visual demonstration of the task improves learning compared to just giving a block of demonstrations before practice

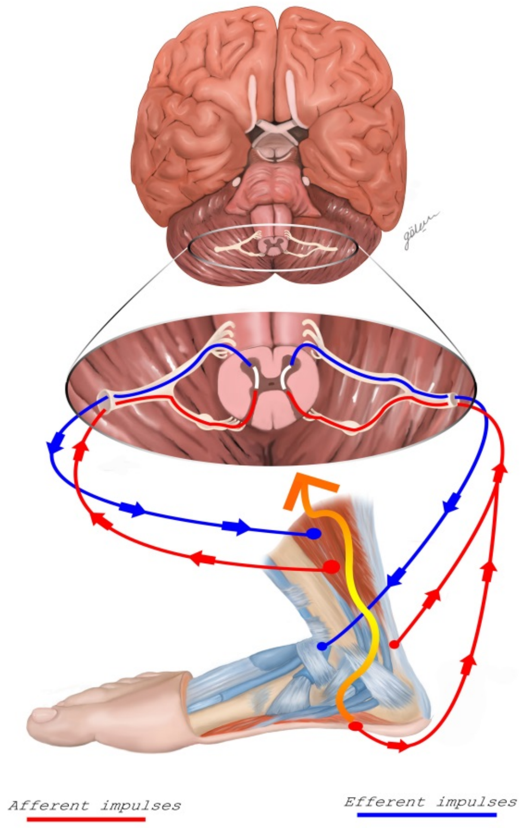
Information

- Feedback
  - Sensory feedback is essential for learning references of correctness which allow us to detect errors from sensory information
  - Can be visual, auditory, olfactory, gustatory, somatosensory
  - Feedback is required to learn unfamiliar tasks



Information

- Inherent Feedback
  - Sensory feedback with meaningful movements determines effectiveness of training.
  - Synchronization of afferent feedback with voluntary movement is useful for motor recovery facilitating neural plasticity
  - Afferent input is important for locomotor pattern and effectiveness of training



Information

- Augmented Feedback
  - Augmented Feedback is a major factor to influence motor learning unless the same information is contained in the inherent feedback.
  - Usefulness of Augmented Feedback
    - Because inherent feedback mechanisms are often impaired augmented feedback can be of even greater importance for rehabilitation
  - Effect of Augmented feedback
    - Increases the rate of skill acquisition, promotes more efficient movements and encourages learning
    - Has no beneficial effect if inherent feedback provides already the same information

Information

- Guidance
  - A procedure used to direct (either physically, verbally and/or visually) learners through task performance in an effort to reduce errors or reduce fears.
  - Guidance should probably be kept to a minimum unless there is danger of injuring oneself or the task is to complex or not possible without it.
  - Probably most useful for early practice and slow tasks

Schmidt and Wrisberg, 2008

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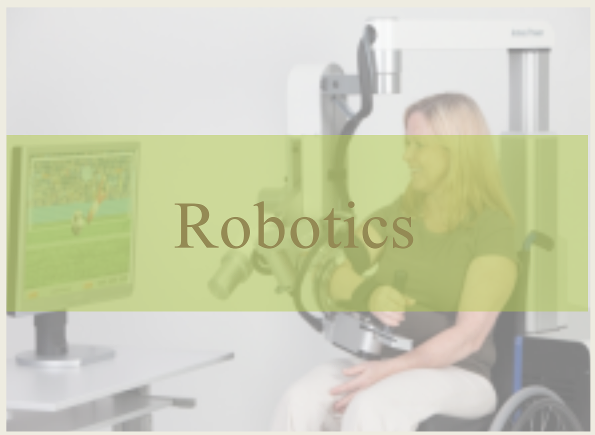
Lessons Learned

- Key factors underlying motor learning can drive neuroplasticity and recovery.
- Therapy needs to be intensive, active and challenging for recovery to take place.
- Therapy should start early and focus on specific tasks related to activities of daily living.
- Practice should be variable and intermix different tasks while therapy goals should be approached in small steps reinforcing patient's progress.
- Motivation is very important for an effective therapy and can be increased by making the training enjoyable and goal-oriented.
- Instructions play an important role but need to be carefully chosen.
- Feedback and guidance should be provided early during therapy but be reduced with time to avoid a dependency on it.

Introduction to Rehabilitation Robotics

TECHNOLOGIES FOR REHABILITATION

Technologies

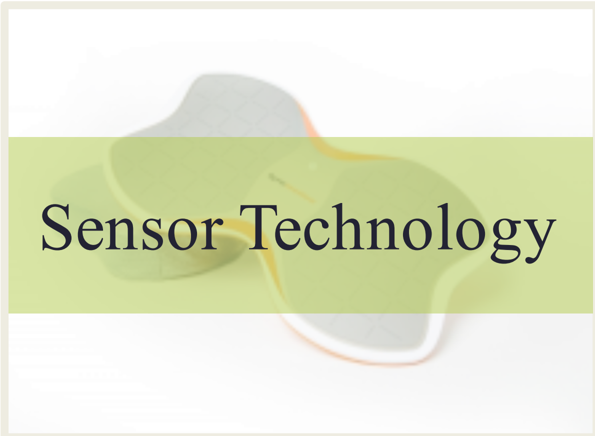


«Application of robotic devices to assist, enhance and intensify therapy.»

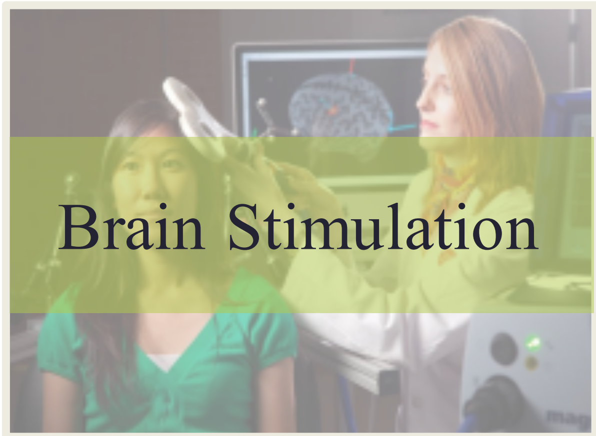
«Use of non-actuated devices (no motors) such as body weight support systems to facilitate rehabilitation.»

«Application of electrical stimulation to create functional movements and improve recovery.»

«Use of virtual reality and environments for enhancing movement therapy.»



«Use of sensors (motion, force etc.) for assessing and enhancing therapy.»



«Application of electrical stimulation to the brain for enhancing recovery.»

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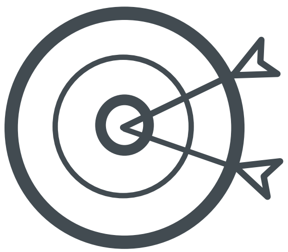
Technologies: Advantages

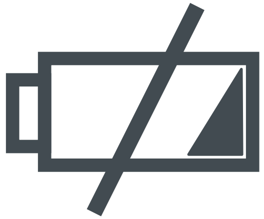
Highly motivating

Greater consistency of therapy



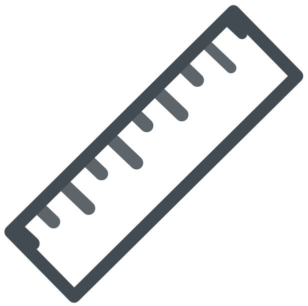
Home use

Never tiring out



Optimized patient support

Precise measurements & assessments



Labor and therapy costs saving

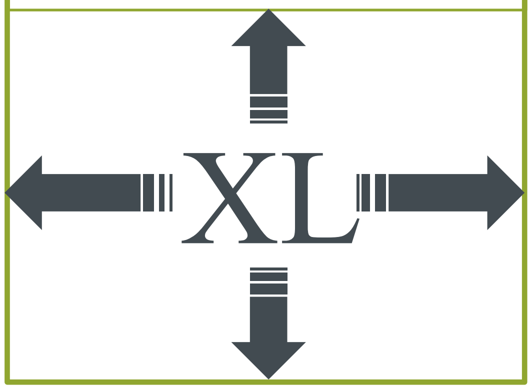
Technologies: Issues

Less flexible than therapist

Risk of obsolescence

Costly

Space consuming



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Technologies

Intensity

- Repetitions
- Duration
- Distribution / Frequency
- Effort
- Difficulty

Larger number of repetitions

Increased practice time

(no supervision, home practice,..)

Increased effort (adding resistance,…

Adjustable difficulty (reduce support,adjusting feedback,…

Psychological Factors

- Motivation

Increased motivation

encouraging feedback

Manner

- Task segmentation
- Specificity / Functionality
- Variability
- Initiation
- Shaping

Functional training

Information

- Instructions
- Feedback

augmented feedback

assistance as-needed

verbal, visual

Technologies: Robotics

American Heart Association and Department of Veterans Affairs and Department of Defense:

"Robot-assisted movement therapy can be used as an adjunct to conventional therapy in patients with deficits in arm function to improve motor skills"

Miller E L et al. Stroke. 2010;41:2402-2448

SIZE OF TREATMENT EFFECT →

ESTIMATE OF CERTAINTY (PRECISION) OF TREATMENT EFFECT

American Heart Association	**CLASS I** *Benefit >>> Risk* Procedure/Treatment **SHOULD** be performed/ administered	**CLASS IIa** *Benefit >> Risk* *Additional studies with focused objectives needed* **IT IS REASONABLE** to perform procedure/administer treatment	**CLASS IIb** *Benefit ≥ Risk* *Additional studies with broad objectives needed; additional registry data would be helpful* Procedure/Treatment **MAY BE CONSIDERED**	**CLASS III** *Risk ≥ Benefit* Procedure/Treatment should **NOT** be performed/administered **SINCE IT IS NOT HELPFUL AND MAY BE HARMFUL**
LEVEL A Multiple populations evaluated* Data derived from multiple randomized clinical trials or meta-analyses	■ Recommendation that procedure or treatment is useful/effective ■ Sufficient evidence from multiple randomized trials or meta-analyses	■ Recommendation in favor of treatment or procedure being useful/effective ■ Some conflicting evidence from multiple randomized trials or meta-analyses	■ Recommendation's usefulness/efficacy less well established ■ Greater conflicting evidence from multiple randomized trials or meta-analyses	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Sufficient evidence from multiple randomized trials or meta-analyses
LEVEL B Limited populations evaluated* Data derived from a single randomized trial or nonrandomized studies	■ Recommendation that procedure or treatment is useful/effective ■ Evidence from single randomized trial or nonrandomized studies	■ Recommendation in favor of treatment or procedure being useful/effective ■ Some conflicting evidence from single randomized trial or nonrandomized studies	■ Recommendation's usefulness/efficacy less well established ■ Greater conflicting evidence from single randomized trial or nonrandomized studies	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Evidence from single randomized trial or nonrandomized studies
LEVEL C Very limited populations evaluated* Only consensus opinion of experts, case studies, or standard of care	■ Recommendation that procedure or treatment is useful/effective ■ Only expert opinion, case studies, or standard of care	■ Recommendation in favor of treatment or procedure being useful/effective ■ Only diverging expert opinion, case studies, or standard of care	■ Recommendation's usefulness/efficacy less well established ■ Only diverging expert opinion, case studies, or standard of care	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Only expert opinion, case studies, or standard of care
Suggested phrases for writing recommendations†	should is recommended is indicated is useful/effective/beneficial	is reasonable can be useful/effective/beneficial is probably recommended or indicated	may/might be considered may/might be reasonable usefulness/effectiveness is unknown/unclear/uncertain or not well established	is not recommended is not indicated should not is not useful/effective/beneficial may be harmful

Technologies

- New technologies have many advantages for application in therapy and a few issues.

- New technologies can provide more intensive and longer trainings adjusted to the individual patient level enhancing capacity for recovery.

- Practice can be scheduled efficiently in a task specific and variable manner.

- Many options exist to provide a much higher motivation than compared to conventional therapy.

- A great number of ways for timed and precise instructions as well as presentation of feedback are available.

Introduction to Rehabilitation Robotics

HISTORY OF REHABILITATION ROBOTICS

History of rehab robotics- UE

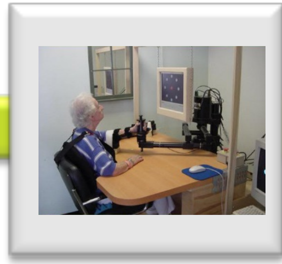
Robotics

1954
Unimate
First robotic arm

1975 Programmable Universal Manipulation Arm (PUMA)

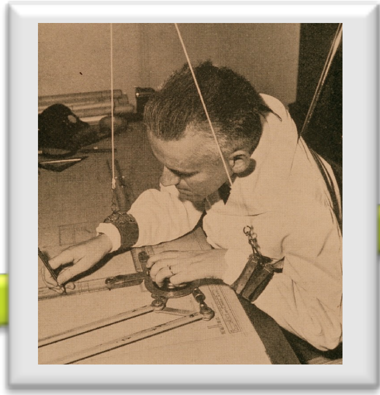
1979 Selective Compliant Articulated Robot Arm (SCARA)

1991
MIT-Manus
First therapeutic arm robot



Rehabilitation Robotics

1920
Movement therapy
Occupational arm training



Rehabilitation

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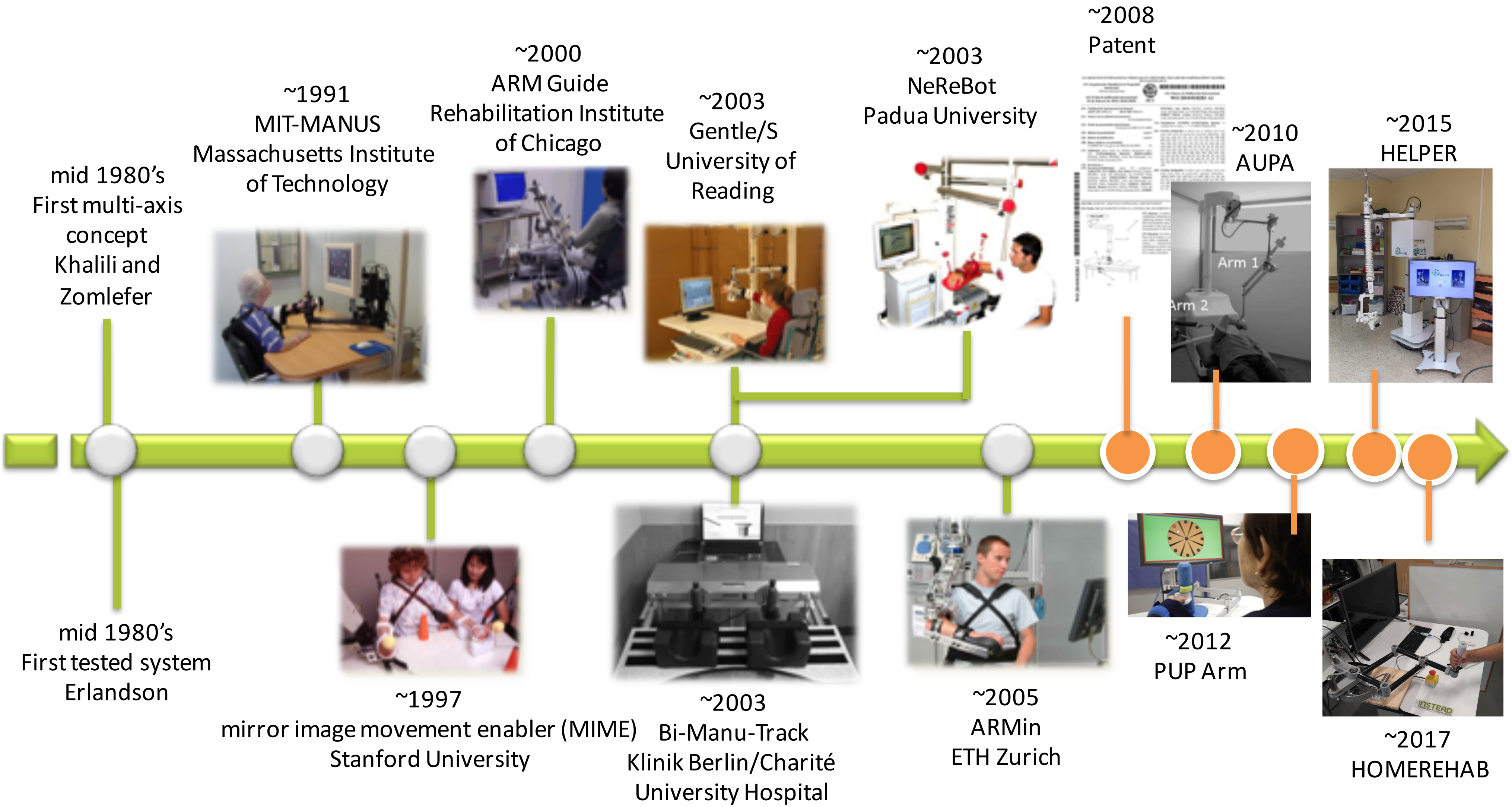
History of rehab robotics- UE



History of rehab robotics- LE

Robotics

1971
Hardiman
First robotic exoskeleton

1999
Lokomat
early driven gait orthosis

~1995
Manual treadmill
training

Rehabilitation

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History of rehab robotics- LE

~1999
Lokomat
(Hocoma)

~1999
Gait Trainer GT-1
(Reha Stim)

~2002
Reo/AutoAmbulator
(Health South, Motorika)

~2008
Lopes
(van Asseldonk et al.)

~2008
Haptic Walker
(Hussein et al.)

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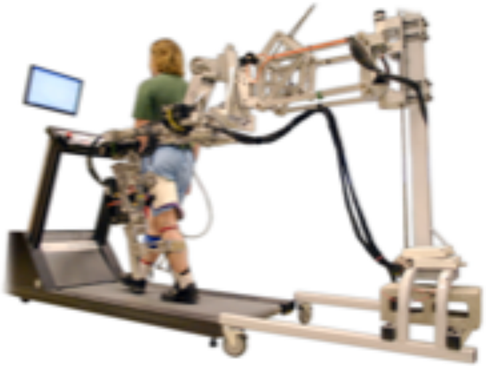
History of rehab robotics- LE



2009
PowerKnee
Tibion PK 100
(Horst)

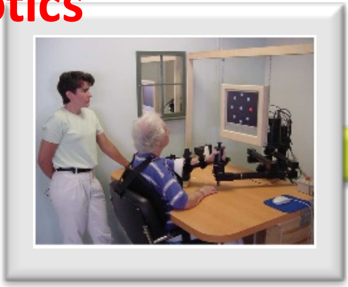
~2009
ALEX
(University of Delaware)

~2010
Anklebot
(Khanna)

~2010
G-EO-System
(Health South, Motorika)

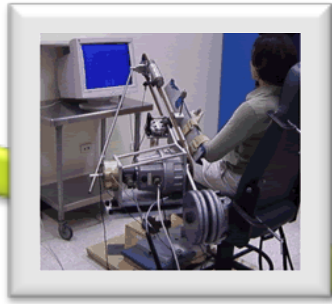
History of rehab robotics- Non Actuaror devices

Rehabilitation Robotics



1991
MIT-Manus
First therapeutic arm robot

1997
MIME



2000
ARM Guide

2005
T-WREX

Non-actuator devices

1920
Movement therapy
Occupational arm training

Rehabilitation

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History of rehab robotics- Non Actuaror devices

~ 2005

T-WREX

~ 2007

Dampace

~ 2011

HandSOME

Gravity balanced orthosis

~ 2003

Freebal

~ 2007

ZeroG passive

~ 2010

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