Audience

Clinicians
Scientists
Engineers
Others

Basic Knowledge - A Movement Therapy Perspective
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2. Key Factors for Recovery
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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.
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.
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).
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

- 31% require assistance
- 20% need help walking
- 16% institutionalized
- 71% vocationally impaired after 7 years
- 34% unemployed at <65 years

[113] [114]
Mechanisms of Recovery

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

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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.
Activity-Induced Neuroplasticity

Active training enhances neuroplasticity and results in reorganization of cortical maps.
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.
KEY FACTORS FOR RECOVERY
Neuroplasticity and learning can be driven by several key factors taken from motor learning theory.
Intensity: Overview

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

Therapy needs to be intensive, active and challenging for optimal recovery to take place.
Intensity: Overview

Intensity = Frequency × Duration × Effort × Difficulty of task

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Intensity: Repetitions

**Power law of practice**

“All other things being equal, the degree of performance improvement depends on the amount of practice [1,2].”

**More is better**

Increasing the amount of task repetitions results in cortical changes and better functional improvement [11-13, 17].”

**How much is enough?**

Evidence from animal and human studies suggests a much higher amount of repetitions for upper [3-7] and lower limbs [8-10] compared to the current therapy standard [31-32].

More repetitions lead to improved outcomes. A minimal amount of repetitions might be required for recovery to take place.
Intensity: Duration

Practice Duration
Duration of practice is a key factor in meaningful training after stroke, and additional practice is better [33-36].

Average therapy session
Inpatients in the UK receive on average 30.6 minutes physical therapy per day of therapy [16].

Optimal practice duration
According to Wang et al. the threshold duration for optimal outcome in stroke inpatients is 3 hours of therapy per day [36].

In general, more therapy hours results in better outcomes. Due to cost and limited manpower current therapies provide only low therapy times.
Intensity: Distribution and Frequency

Benefits of rest periods
Frequent and longer rest periods between repetitions (distributed practice) improve learning compared to no rests (massed practice) in healthy subjects[14].

Trade-off
Massed practice enables increased amounts of training per time. On the other hand resultant fatigue and tiredness of massing practice increase the chance of injury.

There is weak evidence that distributed practice might be better for a safe and effective therapy than massed practice.
Intensity: Effort

Importance of physical effort
Active generation of controlled movements are necessary for effective learning [18-19, 38, 21].

Disadvantage of too much assistance
Movement assistance can reduce physical effort and therefore diminish skill learning [39].
Increasing task difficulty can lead to increased effort [22]

Optimal cognitive demands
Increasing levels of mental effort up to a point are generally beneficial for learning [40-42].
Overwhelming patients on the other hand interferes with learning [43].

Patients should participate as actively as possible and be cognitively challenged without being overwhelmed.
Intensity: Difficulty

Challenge beyond present capabilities
Learning is optimal when difficulty is out of “comfort zone”. More complex tasks enhance short and long term neuronal changes [20].

Enable training in optimal conditions
Support and guidance can help to avoid “over-challenge”.

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

#### 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 reinforcement

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*Therapy should start early, focus on practice of tasks used in daily life and include a high amount of variability.*
Manner: Task segmentation

Types of task segmentation

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.

Benefits of part training

Serial tasks containing distinct segments can be learned more effective in parts [23-24].

Segmentation of complex tasks can enhance performance in stroke patients [44].

Benefits of whole training

Continuous tasks such as walking and fast, discrete tasks should be learned as whole [1].

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.
Manner: Specificity / Functionality

Benefit of task specific training
Task oriented training improves function and changes cortical activation [27, 62].

Make it more real!
Practice with real objects significantly improves reaching kinematics [63, 64].

Shorter movements when grasping a cup if the intention is to drink compared to just taking it [26].

Transfer of practice
Practice conditions need to match the real life situation as close as possible to facilitate daily tasks [25].

Patients should focus practice on activities essential in daily-life in a setting which is as realistic as possible.
Benefits of variable practice
Task variability improves learning and increases the ability to perform new tasks [28-29].

Forgetting helps remembering
Alternating randomly between training of multiple tasks (random practice) seems to be more effective than constant practice (blocked practice) in improving motor function in stroke patients [15].

Dependency on nature of task
Relative timing of closed tasks might be more effectively learned by constant practice [30].

In general, practicing a task with variable setting or in a random order improves learning and the ability to generalize.
Manner: Initiation

Very early, intense therapy might be harmful
Some animal studies have shown worse outcomes if therapy started with high intensity right after a stroke [47].

Window of opportunity
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 [52, 65, 93].

Benefits of early mobilization
Early mobilization reduces medical complications and decreases time to achieve functional walking [88].

⚠️ Current evidence suggests to start rehabilitation early after the incident.
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.”

Wolf et al. 2002

Benefits of shaping

Shaping is an important way for enhancing recovery success, especially in the upper limbs [45-46].

Shaping can be combined with constraining of the unaffected limb to further increase effectivity [46].

Optimal motivation level

Shaping is important to avoid frustration but also to avoid boredom [67].

Adjusting task challenge in small steps while encouraging (reinforcing) improvement is an effective practice method.
Psychological Factors: Overview

Motivation is very important for adhering to intensive therapy and leads to improved training outcomes.

Psychological Factors

- Motivation

  Motivation to practice and perform tasks
Psychological Factors: Motivation

Effect of Motivation
Patient motivation is key factor for a positive rehabilitation outcome [48-49].

Low Motivation
Lack of motivation is a major cause of failure to benefit from rehabilitation [50].

In addition, rehabilitation staff and family members report low motivation as one of the most debilitating symptoms they deal with in rehabilitation [51].

❗ Motivation has a strong influence on successful rehabilitation. Low motivation negatively affects patients, rehabilitation staff and family members.
Psychological Factors: Motivation

Making the task seem important
Adding meaning to exercises can serve as an intrinsic motivator and enhance performance [53].

Effect of Goal-setting
Specific goals that are adjusted during practice lead to improved learning compared to telling people to do their best [54].

Benefits of positive feedback
Positive (normative) feedback has a motivational effect that can enhance learning [55].

⚠️ There exist a variety of ways to increase motivation can be increased which benefit learning.
Information: Overview

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

- Instructions
- Feedback

Information given before practice to facilitate correct performance

Information signaling outcome and correctness of performance
Information: Instructions

Effect of instructions
The way instructions change a subject's focus can have detrimental effects on performance and learning [56].

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 [1].

Optimal schedule
Interspersing active practice with visual demonstration of the task improves learning compared to just giving a block of demonstrations before practice [58-61].

⚠️ Instructions can assist with learning if used in the right way (sparsely intermixed with practice).
Information: Feedback Overview

- Feedback plays an essential role for movement control and learning
- Can be visual, auditory, olfactory, gustatory, somatosensory
- Used to compare an actual movement with the desired movement to detect errors and guide optimal movement form
- Feedback is required to learn unfamiliar tasks

Sensory feedback is essential for learning references of correctness which allow us to detect errors from sensory information.
Information: Feedback Types

- Basic Knowledge
- A Movement Therapy Perspective

Feedback Types:

- Knowledge of Results (KR)
- Knowledge of Performance (KP)

Feedback:

- Inherent (Intrinsic)
  - Proprioceptive
  - Exteroceptive
    - Visual
    - Auditory
    - Tactile

- Augmented (Extrinsic)
  - Knowledge of Results (KR)
  - Knowledge of Performance (KP)
Information: Inherent Feedback

Upper limbs
Synchronization of afferent feedback with voluntary movement is useful for motor recovery facilitating neural plasticity [77-78].

Lower limbs
Afferent input is important for locomotor pattern and effectiveness of training [79].

Sensory feedback with meaningful movements determines effectiveness of training.
Usefulness of Augmented Feedback
Augmented feedback is a major element for motor optimization [66-67, 69].

Because inherent feedback mechanisms are often impaired augmented feedback can be of even greater importance for rehabilitation [68].

Effect of Augmented feedback
Increases the rate of skill acquisition, promotes more efficient movements and encourages learning [70].

Has no beneficial effect if inherent feedback provides already the same information [71].

Augmented Feedback is a major factor to influence motor learning unless the same information is contained in the inherent feedback.
Information: Augmented Feedback

Detrimental effect of Feedback - «Guidance hypothesis»
Learner can become dependent on augmented feedback, possibly at the expense of relying on his own inherent sources of sensory information to support performance under nonaugmented test conditions [69, 94, 95].

Optimal use of Feedback
Performance is optimal when acquisition and subsequent test conditions are similar in terms of available feedback sources [96].

Simple motor skills
Providing feedback about the outcome benefits learning of simple motor skills [97].
Learning in simple tasks can be increased by reducing or delaying the presentation of augmented feedback [98].
Augmented feedback should generally be given in the beginning of therapy but reduced over time to prevent dependency.
**Positive and negative feedback**

Feedback after good trials compared to poor trials enhances learning [102,103].

Feedback indicating errors might heighten self-related concerns or worries that may negatively affect learning.

The mere conviction of being ‘good’ or ‘better than average’ enhances learning [104].

**Self-controlled feedback**

Leads to more effective learning than predetermined feedback schedules [105].

⚠️ Feedback cannot merely be viewed as information without any affective connotation.
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.

*Schmidt and Wrisberg, 2008*

**Effect of Guidance**
Guidance is in general detrimental for learning [106-108]. But interspersed with active practice guidance can be beneficial [109-110].

**Benefit of Guidance**
Useful for preventing injury and reduce fear [1].

Probably most useful for early practice and slow tasks [1].

Learning of complex tasks can benefit from guidance [111, 112].

⚠️ Guidance should probably be kept to a minimum unless there is danger of injuring oneself or the task is too complex or not possible without it.
## Summary: Key Factors of Recovery

- 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.
3

LINKAGE TO NEW TECHNOLOGIES
New Technologies: Overview

Robotics

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

Non-Actuator Devices

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

Functional Electrical Stimulation

«Application of electrical stimulation to create functional movements and improve recovery.»
New Technologies: Overview

- **Virtual Reality**
  «Use of virtual reality and environments for enhancing movement therapy.»

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

- **Brain Stimulation**
  «Application of electrical stimulation to the brain for enhancing recovery.»
## Advantages of New Technologies

<table>
<thead>
<tr>
<th>Greater consistency of therapy</th>
<th>Home use</th>
<th>Never tiring out</th>
<th>Highly motivating</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Target" /></td>
<td><img src="image" alt="House" /></td>
<td><img src="image" alt="Battery" /></td>
<td><img src="image" alt="Smiley" /></td>
</tr>
<tr>
<td>Optimized patient support</td>
<td>Precise measurements &amp; assessments</td>
<td>Labor and therapy costs saving</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Patients" /></td>
<td><img src="image" alt="Ruler" /></td>
<td><img src="image" alt="Crossed Axe" /></td>
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</tbody>
</table>

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## Issues of New Technologies

<table>
<thead>
<tr>
<th>Less flexible than therapist</th>
<th>Risk of obsolescence</th>
<th>Costly</th>
<th>Space consuming</th>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="Less flexible than therapist" /></td>
<td><img src="image2" alt="Risk of obsolescence" /></td>
<td><img src="image3" alt="Costly" /></td>
<td><img src="image4" alt="Space consuming" /></td>
</tr>
</tbody>
</table>
Linkage to New Technologies

Larger number of repetitions
- automated administration [72]
- assistance for impaired patients [73-74]

Increased practice time
- high motivation [75]
- lesser need for supervision
- home-based practice [76]
Linkage to New Technologies

**Increased effort**
- adding resistance [80, 81]
- increased motivation

**Adjustable difficulty** [72]
- added resistance
- reduced support
- adjusting feedback
Linkage to New Technologies

Task simplification
- bilateral/unilateral practice [82]
- partial movements [83]
- reduction of degrees of freedom

Functional training [84, 85]
- simulate virtually with haptic feedback
- in reality combined with accurate sensing
Linkage to New Technologies

**Shaping**
- step by step adaption of task complexity (assistance, resistance)

**Motivation**
- immersion through gamification [80, 87, 89]
- encouraging feedback
- goal-setting [90]
- success through assistance [90]
Linkage to New Technologies

Instructions

- verbal, visual [91-92]

Feedback

- inherent feedback
- augmented feedback
- precise timing
- assistance as-needed
Summary: Linkage to New Technologies

- New technologies have many advantages for application in therapy.
- Some new technologies still have a few issues which are normally outweighed by the advantages.
- 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.
International Industry Society in Advanced Rehabilitation Technology (IISART)

General Information
info@iisartonline.org
www.iisartonline.org
Literature

[8] Cha et al. 2007, Locomotor ability in spinal rats is dependent on the amount of activity imposed on the hindlimbs during treadmill training.
[16] Royal college of physicians clinical effectiveness and evaluation unit on behalf of the intercollegiate stroke working party (2013)
[20] Muir and Jones 2009, Is neuroplasticity promoted by task complexity?
Literature


[31] Lang et al. 2009, Observation of amounts of movement practice provided during stroke rehabilitation.


[33] Langhorne et al. 2011, Stroke rehabilitation.

[34] Bode et al. 2004, Relative importance of rehabilitation therapy characteristics on functional outcomes for persons with stroke.


[38] Newell 1991, Motor skill acquisition.


[42] Rizzolatti and Sinigaglia 2006, So quel che fai: il cervello che agisce e i neuroni specchio.


[45] van der Lee et al. 2001, Constraint-induced therapy for stroke: More of the same or something completely different?


[47] Schallert et al. 2003, Should the injured and intact hemispheres be treated differently during the early phases of physical restorative therapy in experimental stroke or parkinsonism?


[49] Clark and Smith 1999, Psychological correlates of outcome following rehabilitation from stroke.

Literature


[52] Paolucci et al. 2000, Early versus delayed inpatient stroke rehabilitation: a matched comparison conducted in Italy.


[54] Boyce 1992, Effects of assigned versus participant-set goals on skill acquisition and retention of a selected shooting task.


[56] Wulf et al. 2003, Enhancing the learning of sport skills through an external focus of attention.


[59] Shea et al. 1999, Enhancing motor learning through external-focus instructions and feedback.


[67] Hømberg 2013, Neurorehabilitation approaches to facilitate motor recovery.


[70] Magill 1994, The influence of augmented feedback on skill depends on characteristics of the skill and the learner.


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Literature


(82) Trlep et al. 2012, *Skill transfer from symmetric and asymmetric bimanual training using a robotic system to single limb performance.*

(83) Squeri et al. 2012, *Two hands, one perception: How bimanual haptic information is combined by the brain.*


(85) Timmermans et al. 2010, *Sensor-based arm skill training in chronic stroke patients: Results on treatment outcome, patient motivation, and system usability.*


(90) Mihelj et al. 2012, *Virtual rehabilitation environment using principles of intrinsic motivation and game design.*


(92) Imam and Jarus 2014, *Virtual reality rehabilitation from social cognitive and motor learning theoretical perspectives in stroke population.*


(98) Weinstein and Schmidt 1990, *Reduced frequency of knowledge of results enhances motor skill learning.*
Literature

[99] Wulf and Shea 2004, Understanding the role of augmented feedback: The good, the bad and the ugly.

[100] Michaelsen et al. 2006, Task-specific training with trunk restraint on arm recovery in stroke: Randomized control trial.


[107] Singer and Pease 1976, The effect of different instructional strategies on learning, retention, and transfer of a serial motor task.


[109] Hagman 1983, Presentation and test-trial effects on acquisition and retention of distance and location.


Image sources

Slide 2 – Audience

Slide 5 – Basic Neuroanatomy
Left, middle, right images: Created for slide pool by Gokcen Akcali

Slide 6 – Neuronal Transmission
Left, middle, right images: Created for slide pool by Gokcen Akcali

Slide 7 – CNS Injuries
Left image: http://www.pialaw.ca/
Middle image: http://www.merckmanuals.com/

Slide 8 – Motor Impairments after Stroke
Left Image: http://www.rgbstock.com/bigphoto/n3hzesC/Old+man
Right Image (rollator): https://plus.google.com/+VomrheinDe/posts/HdJcmQh3ZNE

Slide 9 – Mechanisms of Recovery
Image sources

Slide 10 – Neuroplasticity
Series from: Taub et al. 2002, New treatments in neurorehabilitation founded on basic research

Slide 11 – Activity-Induced Neuroplasticity
Monkey brain: http://upload.wikimedia.org/wikipedia/en/d/d9/Motor_Cortex_monkey.jpg
Cortex areas: Nudo et al. 2001, Role of adaptive plasticity in recovery of function after damage to motor cortex

Slide 14 – Key Factors for Recovery
Central image: Slide from Clemens

Slide 17 – Intensity: Repetitions
Graph: Adapted from: Ericsson et al. 1993, The role of deliberate practice

Slide 18 – Intensity: Duration
Graph: Created for slide pool

Slide 19 – Intensity: Distribution and Frequency
Graph: Schmidt and Lee 2005, Motor control and learning

Slide 21 – Intensity: Difficulty
Graph: Adapted from Guadagnoli and Lee 2004, Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning

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Image sources

Slide 24 – Manner: Specificity / Functionality

Slide 27 – Manner: Shaping
Graph: Created for slide pool

Slide 29 – Psychological Factors: Motivation
Graph: Adapted from Daniel Coyle 2009, The talent code: Greatness Isn’t Born. It’s Grown. Here’s How.

Slide 34 – Information: Feedback Types
Left image: Tennis stroke: http://www.optimumtennis.net/images/federer-forehand-grip.jpg

Slide 35 – Information: Inherent Feedback
Image: Slide/image from Clemens

Slide 38 – Information: Augmented Feedback
Graph: Created for slide pool

Slide 43 – New Technologies: Overview
Robotics: http://products.iisartonline.org/products/22/photos/22.jpg
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Virtual Reality: http://products.iisartonline.org/products/60/photos/60.jpg
Sensor technology: http://products.iisartonline.org/products/49/photos/49.jpg
Brain stimulation: http://psychiatry.duke.edu/files/pictures/072911_lisanby011_fpo.jpg

Slide 45 – Advantages of New Technologies

Icons: Adapted for this slide pool

Slide 46 – Issues of New Technologies

Icons: Adapted for this slide pool

Slide 47 – Linkage to New Technologies

Repetitions: Hocoma image

Slide 48 – Linkage to New Technologies

Increased effort http://c1.staticflickr.com/1/82/244870160_4f6de4dbaa_z.jpg, Tug of War by toffehoff via Flickr.
Creative Commons: https://creativecommons.org/licenses/by-sa/2.0/legalcode
Image sources

Slide 49 – Linkage to New Technologies
Segmentation: Created for this slide pool
Specific training: Hocoma

Slide 50 – Linkage to New Technologies
Shaping: Created for this slide pool
Motivation: Created for this slide pool

Slide 51 – Linkage to New Technologies
Instructions: http://informatics.northwestern.edu/blog/wp-content/uploads/2012/01/ikea_assembly_instructions.jpg
Feedback: Adapted for this slide pool (Slide from Clemens)