Outline

- Definition of Neurorehabilitation
- International Classification of Functioning, Disability and Health (ICF)
- Neurological rehabilitation
- Physiological consequences of CNS damage
DEFINITION OF NEUROREHABILITATION
Disease, illness and sickness

- **Disease (Enfermedad)**: what the doctor diagnoses and treats.
  - Based on *signs* (observations)

- **Illness (Dolencia)**: Patient’s experience of the disease.
  - Yields *symptoms* (reported)

- **Sickness (Malestar)**: Social condition applying to people with a disease.
Rehabilitation is the branch of medicine aiming to restore function and enhance quality of life of those with impairments or disabilities.

- Modified from [Wikipedia:Rehabilitation]

Rehabilitation is the process through which a disabled person is helped to acquire knowledge and skills in order to maximise their physical, psychological and social functioning.

Neurorehabilitation

“Neurorehabilitation is the clinical subspecialty devoted to the restoration and maximization of functions that have been lost due to impairments caused by injury or disease of the nervous system.”

[Selzer, Textbook of Neural Repair and Rehabilitation, Vol 1.]

Injury or disease of the nervous system can lead to deficiencies:

- Cognitive
- Perceptual
- Physical
- Behavioural / Emotional
Neurorehabilitation

There are two types of brain injury:

- **Traumatic Brain Injury (TBI)** is caused by an external force.
  - It may be caused by a blow to the head, that causes the brain to move inside the skull or damages the skull. This in turn damages the brain.

- **Acquired Brain Injury (ABI)** occurs at the cellular level. It is most often associated with pressure on the brain.
  - It may be caused by a tumour, neurological illness, stroke, abuse of drugs, etc.

Source: [http://www.webmd.boo...blems-causes-treatments]
Neurorehabilitation

- **(Neuro)plasticity** is the ability of neurons and neuron aggregates to adjust their activity and even their morphology to alterations in their environment or patterns of use.

  - [Selzer, Textbook of Neural Repair and Rehabilitation, Vol 1.]
Neural Repair refers to the range of interventions by which neuronal circuits lost to injury or disease can be restored.

[Selzer, Textbook of Neural Repair and Rehabilitation, Vol 1.]

Figure from:
[http://carmichaellab.neurology.ucla.edu/integrated-view-neural-repair-after-stroke]
INTERNATIONAL CLASSIFICATION OF FUNCTIONING, DISABILITY AND HEALTH (ICF)
What is the International Classification of Functioning, Disability and Health (ICF)?

- The **ICF** is one of a family of international classifications developed by the WHO for application to various aspects of health.
  - (e.g. diagnosis, functioning and disability, reasons for contact with health services, etc)
- These classifications:
  - Define standardized common unified and standard language and descriptive framework permitting communication about health and health care across the world in various disciplines and sciences.
  - Provide valuable tools to describe and compare the health of populations in an international context
What is the International Classification of Functioning, Disability and Health (ICF)?

- The **International Classification of Diseases**, Tenth Revision (ICD-10) provides an etiological framework for health conditions (diseases, disorders, injuries, etc.)
  - Helpful for diagnosis

- The ICF instead provides a descriptive framework for health and health-related states.
  - ICF is etiology neutral
  - Helpful for prevention and treatment

* As you might have guessed the ICD is also one of the international classifications by the WHO. There are several other international classifications related to health.

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What is the International Classification of Functioning, Disability and Health (ICF)?

- In particular, the ICF classifies functioning and disability associated with health conditions.
  - **Functioning** is an umbrella term encompassing all body functions, activities and participation.
  - **Disability** serves as an umbrella term for impairments, activity limitations or participation restrictions.
Two persons with the same disease (ICD) can have different levels of functioning (ICF),

... and two persons with the same level of functioning (ICF) do not necessarily have the same health condition (ICD).

Figure from: [Reinhardt JD et al (2009) J Rehabil Med Preview 41: 810–822]
ICF structure

- ICF defines components of **health and** some health-related components of **well-being**; the so called **domains**
  - Health domain
  - Health related domain i.e. well-being (such as education and labour, and other environmental factors)

- Information is organized in 2 parts:
  - Part 1 deals with Functioning and Disability
    - (1) Body Functions and Structures; and
    - (2) Activities and Participation
  - Part 2 covers Contextual Factors
    - (1) Environmental factors
    - (2) Personal factors*

- ICF does not cover circumstances that are not health-related e.g. socioeconomic factors, etc

* Personal factors is also a component of Contextual Factors but they are not classified in ICF because of the large social and cultural variance associated with them.
ICF basic definitions

DEFINITIONS

In the context of health:

**Body functions** are the physiological functions of body systems (including psychological functions).

**Body structures** are anatomical parts of the body such as organs, limbs and their components.

**Impairments** are problems in body function or structure such as a significant deviation or loss.

**Activity** is the execution of a task or action by an individual.

**Participation** is involvement in a life situation.

**Activity limitations** are difficulties an individual may have in executing activities.

**Participation restrictions** are problems an individual may experience in involvement in life situations.

**Environmental factors** make up the physical, social and attitudinal environment in which people live and conduct their lives.

*a.k.a. Disability*

*a.k.a. Handicap*

[Source: ICF, WHO 2001]
The *International Classification of Impairments, Disabilities and Handicaps* (ICIDH) is concerned with the consequences of diseases and provides a framework for management of chronic diseases.

The ICF modernises the ICIDH

- Terms with less negative connotations are used
  - E.g. Activity instead of disability, Participation instead of handicap
- Definitions are updated
- More emphasis is given to social context
Relation ICIDH and ICF

Table 1  Definitions of the WHO’s International Classification of Impairments, Disabilities and Handicaps

<table>
<thead>
<tr>
<th>Impairment</th>
<th>Disability</th>
<th>Handicap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any loss or abnormality of</td>
<td>Any restriction or lack of activity</td>
<td>A disadvantage for a given individual</td>
</tr>
<tr>
<td>psychological, physiological</td>
<td>resulting from an impairment to</td>
<td>resulting from impairment or disability that</td>
</tr>
<tr>
<td>or anatomical structure or</td>
<td>perform an activity in the manner</td>
<td>limits or prevents the fulfillment of a role</td>
</tr>
<tr>
<td>function</td>
<td>or in the range considered normal</td>
<td>that would otherwise be normal for that</td>
</tr>
<tr>
<td></td>
<td>for people of the same age, sex,</td>
<td>individual</td>
</tr>
<tr>
<td></td>
<td>and culture</td>
<td></td>
</tr>
</tbody>
</table>

WHO 1980.

Table 2  New classifications of the International Classification of Functioning and Disability: ICIDH II

<table>
<thead>
<tr>
<th>Impairment</th>
<th>Activity</th>
<th>Contextual factors (participation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The loss or abnormality of</td>
<td>The nature and extent of functioning at the level</td>
<td>Include the features, aspects</td>
</tr>
<tr>
<td>a body structure or of a</td>
<td>of the person. Activities may be limited in nature,</td>
<td>and attributes of objects,</td>
</tr>
<tr>
<td>physiological or psychological</td>
<td>duration, and quality</td>
<td>structures, human made organisations,</td>
</tr>
<tr>
<td>function</td>
<td></td>
<td>service provision, and agencies in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the physical, social, and attitudinal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>environment in which people live and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>conduct their lives. Contextual factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>include both environmental factors and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>personal factors</td>
</tr>
</tbody>
</table>

WHO 1998.

# Overview of ICF

<table>
<thead>
<tr>
<th>Components</th>
<th>Part 1: Functioning and Disability</th>
<th>Part 2: Contextual Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domains</strong></td>
<td>Body functions</td>
<td>Environmental factors</td>
</tr>
<tr>
<td>Body functions</td>
<td>Life areas (tasks, actions)</td>
<td>Personal factors</td>
</tr>
<tr>
<td>Body structures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Constructs          |                                    |                            |
| Change in body      |                                    |                            |
| functions (physiological) |                        |                            |
| Change in body      |                                    |                            |
| structures (anatomical) |                      |                            |
| Performance         |                                    |                            |
| Executing tasks in a |                        |                            |
| standard environment |                     |                            |
| Executing tasks in the |                          |                            |
| current environment  |                      |                            |

| Positive aspect     |                                    |                            |
| Functional and      |                                    |                            |
| structural integrity| Activity limitation                |                            |
|                     | Participation restriction            |                            |

| Negative aspect     |                                    |                            |
| Impairment          |                                    |                            |
| Activity limitation | Activity limitation restriction     |                            |
| Participation       |                                    |                            |
| restriction         |                                    |                            |

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[Source: ICF, WHO 2001]
ICF first level classification*

### Body functions

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Mental functions</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Sensory functions and pain</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Voice and speech functions</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Functions of the cardiovascular, haematological, immunological, and respiratory systems</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Functions of the digestive, metabolic and endocrine systems</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Genitourinary and reproductive functions</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Neuromusculoskeletal and movement-related functions</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Functions of the skin and related structures</td>
</tr>
</tbody>
</table>

### Activities and participation

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Learning and applying knowledge</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>General tasks and demands</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Communication</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Mobility</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Self-care</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Domestic life</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Interpersonal interactions and relationships</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Major life areas</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>Community, social, and civic life</td>
</tr>
</tbody>
</table>

### Body structures

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Structures of the nervous system</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>The eye, ear, and related structures</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Structures involved in voice and speech</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Structures of the cardiovascular, immunological, and respiratory systems</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Structures related to the digestive, metabolic, and endocrine systems</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Structures related to the genitourinary and reproductive systems</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Structures related to movement</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Skin and related structures</td>
</tr>
</tbody>
</table>

### Environmental factors

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Products and technology</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Natural environment and human-made changes to environment</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Support and relationships</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Attitudes</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Services, systems, and policies</td>
</tr>
</tbody>
</table>

* The ICF has 4 levels of classification each one further detailing the previous one.

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A few other definitions of interest from the ICF

- **Motivation**: Mental functions that produce the incentive to act; the conscious or unconscious driving force for action.

- **Attention functions**: Specific mental functions of focusing on an external stimulus or internal experience for the required period of time.

- **Psychomotor control**: Mental functions that regulate the speed of behaviour or response time that involves both motor and psychological components, such as in disruption of control producing psychomotor retardation (moving and speaking slowly; decrease in gesture and spontaneity) or psychomotor excitement (excessive behavioural and cognitive activity, usually nonproductive and often in response to inner tension as in toe-tapping, hand-wringing, agitation, or restlessness.)
A few other definitions of interest from the ICF

- **Higher-level cognitive functions**: Specific mental functions especially dependent on the frontal lobes of the brain, including complex goal-directed behaviours such as decision-making, abstract thinking, planning and carrying out plans, mental flexibility, and deciding which behaviours are appropriate under what circumstances; often called executive functions.

- **Includes**;
  - **Abstraction**: Mental functions of creating general ideas, qualities or characteristics out of, and distinct from, concrete realities, specific objects or actual instances.
NEUROLOGICAL REHABILITATION
ICF key concepts

- **Impairments**: Description. Implies nothing about consequence.
  - Examples: Hemiparesis, sensory loss

- **Activity / Disability**: Limitation. Functional consequence of impairment.
  - Examples: Inability to walk, dressing, etc

- **Participation / Handicap**: Restriction. Social context of the disability. Has implications for rehabilitation.
  - Example: Prevention to enrole in armed forces, maintaining a job, doing sports, etc

ICF functioning model

Source: [ICF, WHO 2001]

ICF functioning model

ICF: Elaboration on ICF-CY by Heerkens et al. and Ghey et al.

Health Condition: (Disease/Disorder)

Functions & Structures (impairments)

Activities (limitations)

Work Participation (restrictions)

Health/Health State

ICD 10

Functioning

(Work related) Environmental Factors:
- Work Content
- Work Relations
- Terms of Employment
- Working Conditions
- Characteristics of the Organisation
- Other Environmental Factors (e.g. legislation, living condition)

Personal Factors:
- General personal data: socio-demographic factors
- General mental Personal Factors
- Disease related factors (including comorbidity)
- Lifestyle
- Work related Personal Factors

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ICF functioning model: Example

Figure from: [Bensoussan L et al (2008) J Rehabil Med 40:497-507]
ICF functioning model: The case of stroke

Figure from: [Langhorne P et al (2011) Lancet 377:1693-702]
Box 2 The medical model of disability

- Disability is individualised. It is regarded as a disease state that is located within an individual. Thus, the problem and solution may both be found within that individual.

- Disability is a disease state, a deviation from the norm, which inherently necessitates some form of treatment or cure.

- Being disabled a person is regarded inherently as biologically or psychologically inferior to an able bodied person.

- Disability is viewed as a personal tragedy. It assumes the presence of a victim.

- The objective normality state that is assumed by professionals gives them a dominant decision making role.

Box 3: Social model of disability

- A person’s impairment is not the cause of restriction of activity
- The cause of restriction is the organisation of society
- Society discriminates against disabled people
- Attitudinal, sensory, architectural, and economic barriers are equally, if not more, important than health barriers
- Less emphasis is placed on the involvement of health professionals in the life of a person with disability

Rehabilitation Process Characteristics

Box 1: The rehabilitation process

- An educational process
- Central involvement of the disabled person in programme planning
- Key involvement of family, friends, and colleagues
- A process that requires clear goals to be set and measured
- An interdisciplinary process
- A process based on the concepts of disability (activity) and handicap (participation)

Rehabilitation Process Tasks

- Basic tasks associated with the rehabilitation process:
  - To work in partnership with the disabled person and their family
  - To give accurate information and advice about the nature of the disability, natural history, prognosis, etc.
  - To listen to the needs and perceptions of the disabled person and their family
  - To work with other professional colleagues in an interdisciplinary fashion
  - To liaise as necessary with key carers and advocates
  - To assist with the establishment of realistic rehabilitation goals, which are both appropriate to that person’s disability and their family, social, and employment needs.

Rehabilitation Process Goals

- Rehabilitation goals must be:
  - Precise.
  - Objective (as opposed to subjective)
  - Susceptible of being monitored

- A useful mnemonic to remember what the goals should be is SMART:
  - Specific
  - Measurable
  - Achievable
  - Relevant
  - Time limited
Measuring goals; measures designed to monitor overall disability, and quality of life and assessing progress

Figure from: [Langhorne P et al (2011) Lancet 377:1693-702]
Fugl-Meyer assessment of motor impairment

Figure 1.
Comparison of sequence of stepwise recovery described by Twitchell and Brunnstrom with the stages and scale items used by Fugl-Meyer et al.

Figure from: [Crow and Harmeling-van der Wel (2008) Phys. Ther. 88:1554-1567]
Fugl-Meyer assessment of motor impairment

Video from YouTube: [https://www.youtube.com/watch?v=0eGS4K0Y59o]

Total time: 3:47
Components of neurorehabilitation

- **Physical rehabilitation**
  - Concerned with physical impairments and movement dysfunctions
  - Aims to increase mobility and function

- **Cognitive rehabilitation**
  - Concerned with cognition impairments
  - Submodalities
    - Aphasia rehabilitation: centered on language disorders

- **Occupational therapy**:
  - Focus on evaluating and improving a person’s functional abilities. Aims at helping people live as independently as possible.
    - NOTE: “Occupation” in the rehabilitation field often refer to “everyday activities”
  - Might incorporate physical and cognitive aspects

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Physical rehabilitation

Figure from: [http://chiropractoringeorgia.com/physical-rehabilitation/]

Figure from: [http://www.hahv.org/service/physical-medicine-rehabilitation-inpatient-rehab]
Occupational Therapy

Total time: 4:42
Only interesting up to 3:41
Cognitive rehabilitation

Figure from: Snapshot from YouTube video [https://www.youtube.com/watch?v=qpMi_2VXvc/]

Figure from: [http://www.cognisoft.info/cognisoft-i.html]
PHYSIOLOGICAL CONSEQUENCES OF CNS DAMAGE
Neurorehabilitation

- “Etiology”: It is the CNS which is damaged, not the muscles

Example of damage caused by a stroke

Figure from: [Shah et al 2013, Front. Hum. NeuroSci, 7:888]
Consequences of CNS damage

- Injury to the adult [mammalian] central nervous system (CNS) is devastating because of the inability of central neurons to regenerate correct axonal and dendritic connections.

- The consequences of injury are not just a break in communication between healthy neurons, but a cascade of events that can lead to neuronal degeneration and cell death.

- However, failure of CNS neurons to regenerate appears to be not an intrinsic deficit of the neuron, but rather a characteristic feature of the damaged environment that did not support regeneration.

Physiological consequence (observable impairment) depends the affected region of the brain.

Figure from: [thebigview.com]

Figure from: [wizardsofads.com.au]
CNS injury

Figure 1 | Schematic representation of the CNS injury site. Injury to the adult CNS often results in the transection of nerve fibres and damage to surrounding tissues. The distal ends of the severed axons form characteristic dystrophic growth cones that are exposed to the damaged glial environment. During the early phase of injury, myelin-associated inhibitors from intact oligodendrocytes and myelin debris can restrict axon regrowth. Recruitment of inflammatory cells and reactive astrocytes over time leads to the formation of a glial scar, often accompanied by a fluid-filled cyst. This scarring process is associated with the increased release of chondroitin sulphate proteoglycans, which can further limit regeneration. Together, these molecular inhibitors of the CNS glial environment present a hostile environment for axon repair.

Figure from: [Yiu and He (2006) Nat. Rev. NeuroSci, 7:617-627]
Cellular mechanisms for gray matter plasticity

Figure from: [Royet et al (2013) Front Psych 4:928]
Functional regeneration

- **Steps to functional regeneration.**
  - Several criteria need to be met before functional regeneration can be validated including
    - Cell survival
    - Axon growth
    - Re-myelination
    - Synapse formation
  - **Descriptive tests** can be used to determine the survival and integrity of the injured system, whether axonal regeneration is present, and if appropriate synaptic connections and remyelination have occurred.
  - **Electrophysiological and pharmacological intervention** can be used to assess the function and specificity of the regenerated pathway.
  - Ultimately, elimination of the regenerated pathway (for example, retranssection) is important to determine its role in any reported functional recovery.

- **Source:** [Horner and Gage (2000) Nature 407:963-970]
Consequences of neuronal injury

- Following a specific traumatic or chemotoxic event, or as a result of ongoing degenerative processes, long-term structural and functional deficits occur in the adult CNS.

- In severe cases, these insults are not repaired or compensated for by surviving systems.

- On a cellular level, these deficits include demyelination, degeneration, abortive or aberrant sprouting, and cell death.

Consequences of neuronal injury

- **Demyelination.**
  - A demyelinated axon may maintain both its afferent and efferent connections but, due to a loss of myelination, poor or failed conduction results.

Consequences of neuronal injury

- **Axonal retraction.**

- Injury to an axon itself or to the original cellular target of the axon can result in [aberrant] degeneration. Presynaptic, retrograde and trans-synaptic degeneration can occur.

- Synaptic conduction across a pathway is lost and a reactive cellular response, including astrocytes and microglia, forms.

Consequences of neuronal injury

- **Sprouting.**
  - Axonal sprouting has been described for surviving neurons. [Horner and Gage (2000) Nature 407:963-970]
  - It can be compensatory arising from preserved fibres.

Figure from: [Yiu and He (2006) Nat. Rev. NeuroSci, 7:617-627]
Consequences of neuronal injury

- **Sprouting.**
  - It is *abortive* when a sprouting axon encounters an inhibitory matrix or scar, loss of neurotrophin support, or the presence of continuing inflammation or toxicity.

- **Aberrant** sprouting can occur when an axon reconnects to an inappropriate target.
  - Synaptic conduction is restored but this pathway does not result in functional restoration.

- **Source:** [Horner and Gage (2000) Nature 407:963-970]
Consequences of neuronal injury

- **Cell death.**
  - When a neuron is completely deprived of its source of growth factors and exposed to high levels of toxic molecules or inflammatory attack, it can undergo cell death.

- These patterns represent the anatomical correlates of brain dysfunction but also the specific processes that must be targeted for repair.

- **Source:** [Horner and Gage (2000) Nature 407:963-970]
Neurorehabilitation: A science still in the making

- Many rehabilitation modalities available; none has demonstrated to be clearly superior to the rest.

- **Problem:** We do not fully understand how the brain rehabilitates from injury.

---

Figure 2: Interventions to improve upper-limb motor recovery after stroke
This figure summarises the results for upper-limb interventions targeting the recovery of arm or hand function, and shows the intervention category, number of trials (participants recruited) plus the SMD and 95% CI for the effect of the intervention on the outcome measure. The most common measures of arm outcome were the action research arm test, motor assessment scale, and the Fugl-Meyer scale. The most common measures of hand function were various peg tests and the hand component of the action research arm test. CMT=constraint-induced movement therapy. EMG=electromyographic biofeedback. SMD=standardised mean difference. *One trial had two subgroups and these were, therefore, analysed as different trials (thus, the number of trials reported is 6). †Two trials had two subgroups, which were analysed as different trials (number of trials reported is 6). ‡One trial had two subgroups, which were analysed as different trials (number of trials reported is 4). §Both trials had two subgroups, which were analysed as different trials (number of trials reported is 4).

Figure from: [Langhorne et al 2009, Lancet Neurology, 8:741-54]
Current rehabilitation treatments have a disappointingly modest effect on impairment early or late after stroke. [Krakauer et al 2012, NNR, 26(8):923-31]

**Problem:** Rehabilitation is applied late (chronic stage) and mostly involves compensatory strategies with minimal impact on impairment.

干预取决于时机

图2：假设性模式恢复中风后的时间与干预策略选择

Neurorehabilitation:
Doing things right

- “Neural plasticity is believed to be the basis for both learning in the intact brain and relearning in the damaged brain that occurs through physical rehabilitation.” [Kleim and Jones (2008), JSLHR, 51(1):S225-39]

- **Question**: How can neurological therapeutic interventions best be delivered to drive neuroplasticity in order to shape recovery after brain injury or disease?

---

### Table 1. Principles of experience-dependent plasticity.

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Use It or Lose It</td>
<td>Failure to drive specific brain functions can lead to functional degradation.</td>
</tr>
<tr>
<td>2. Use It and Improve It</td>
<td>Training that drives a specific brain function can lead to an enhancement of that function.</td>
</tr>
<tr>
<td>3. Specificity</td>
<td>The nature of the training experience dictates the nature of the plasticity.</td>
</tr>
<tr>
<td>5. Intensity Matters</td>
<td>Induction of plasticity requires sufficient training intensity.</td>
</tr>
<tr>
<td>6. Time Matters</td>
<td>Different forms of plasticity occur at different times during training.</td>
</tr>
<tr>
<td>7. Salience Matters</td>
<td>The training experience must be sufficiently salient to induce plasticity.</td>
</tr>
<tr>
<td>8. Age Matters</td>
<td>Training-induced plasticity occurs more readily in younger brains.</td>
</tr>
<tr>
<td>9. Transference</td>
<td>Plasticity in response to one training experience can enhance the acquisition of similar behaviors.</td>
</tr>
<tr>
<td>10. Interference</td>
<td>Plasticity in response to one experience can interfere with the acquisition of other behaviors.</td>
</tr>
</tbody>
</table>

Table from: [Kleim and Jones (2008), JSLHR, 51(1):S225-39]
Brain plasticity

- **Plasticity** is the capacity of the nervous system to change its structure and function with time in reaction to environmental changes [KolbB2010].
  - Plasticity involves a number of physiological processes from molecular events to behavioural and conductual levels.

- Plasticity is in other words, the ability of the brain to change with learning.
  - Plasticity is always present, but it decreases with age, but (locally) peaks after brain injury

Reorganization mechanisms and strategies

Reorganization mechanisms

• Biological and physiological response
• Dictates *when* and *how* reorganization occurs

Reorganization strategies

• Cortical representation
• Dictates *where* reorganization occurs

Mechanisms of functional recovery

- Restitution of non-infarcted penumbral areas
- Resolution of diaschisis
- Tissue repair; Synaptic sprouting, unmasking (enforcement) of existing neural circuits and development of fresh synaptic connections.
- Behavioural compensation; compensation strategies.
Reorganization mechanisms

Momento del infarto

+ Desenmascarado de sinapsis latentes
+ Resolución de edema
+ Re-vascularizado y nuevo riego de la penumbra isquémica

Semana inicial

Plasticidad real

+ Recuperación espontánea

Crecimiento de nuevas conexiones

2 semanas

Corto plazo

Largo plazo

3 meses

+ Potenciación de largo plazo (LTP)
+ Regeneración axonal y surgimiento y desarrollo de nuevas sinapsis

Tiempo desde el infarto

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# Reorganization strategies

## Table 2. Common functional reorganization strategies following stroke affecting the motor cortex

<table>
<thead>
<tr>
<th>Reorganization strategy</th>
<th>Functional interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipsilesional activation of M (^{21,22})</td>
<td>Activation shifts toward infarct rim (perilesional activation) or posterior and occasionally inferior extension. The shift may represent neural unmasking or disinhibition of existing latent connections or recruitment of new neurons not normally devoted to motor functions (vicariance) and establishment of new synapsis.</td>
</tr>
<tr>
<td>Contralesional activation of the M (^{22,32})</td>
<td>The unaffected contralesional primary motor cortex undertakes the duties of its damaged counterpart. Often regarded as less efficient than ipsilesional activation, it may indicate an unconscious lack of effort.</td>
</tr>
<tr>
<td>Bilateral recruiting of secondary motor areas (SMA, PM)(^{21,33,35})</td>
<td>PM becomes overactivated at a late stage of recovery, indicating a redistribution of workload. It may reflect recruitment of pre-existing large-scale distributed motor network rather than genuine reorganization. Even simple tasks become complex for patients. Thus, it may reflect an increase in executive control. (SMA and PM are associated with executing complex tasks.)</td>
</tr>
<tr>
<td>Recruitment of nonmotor areas (PFC, PPC, ACC, and insula)(^{21,33,35,36})</td>
<td>May reflect cortical compensatory cognitive strategies. Lesser attenuation with time suggests recourse to normal behavior; compensatory strategies become less necessary as recovery progresses.</td>
</tr>
<tr>
<td>Recruitment of the cerebellum(^{27})</td>
<td>Cerebellar activation may be a consequence of its role in motor learning or haemodynamic alterations such as diaschisis. Change in cerebellar activity ipsilateral to the paretic side is associated with good prognosis. Activation of cerebellum ipsilateral to injury increases transiently after stroke regardless of the recovery.</td>
</tr>
<tr>
<td>Recruitment of the basal ganglia(^{33})</td>
<td>Cerebellar activation may originate in subcortical structures such as thalamus and basal ganglia; the latter is involved in motor skill learning. fMRI is not well suited for the study of the basal ganglia, and thus this strategy is not further considered in this study.</td>
</tr>
<tr>
<td>Swerving of the CST(^{10})</td>
<td>Damage of the brainstem could block propagation of motor signal. If damaged, the new tract may join the pons further down. We focus on lesions on the primary motor cortex and thus do not consider this strategy here.</td>
</tr>
</tbody>
</table>

*Note: ACC = anterior cingulate cortex; CST = cortico-spinal tract; fMRI = functional magnetic resonance imaging; M1 = primary motor cortex; PFC = (dorsolateral) prefrontal cortex; PM = premotor cortex; PPC = posterior parietal cortex; SMA = supplementary motor area.*
Different reorganization strategies have different prognosis associated

Plasticity and cortical reorganization can to a extent be influenced and guided by rehabilitation therapy.
- Therapies should aim at fostering the most beneficial reorganization

Understanding functional reorganization associated to rehabilitation:
- Supports therapy planning.
- Optimizes therapy platform design to maximize their impact.
- Permits identification of neurophysiological benefits in terms of motor retraining (and away from compensatory strategies).

Impact of plasticity in rehabilitation

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THANKS, QUESTIONS?
BACK UP
Applications of ICF*

- As a statistical tool - in the collection and recording of data (e.g. in population studies and surveys or in management information systems);

- As a research tool - to measure outcomes, quality of life or environmental factors;

- As a clinical tool - in needs assessment, matching treatments with specific conditions, vocational assessment, rehabilitation and outcome evaluation;

- As a social policy tool - in social security planning, compensation systems and policy design and implementation; also used by sectors such as insurance, social security, labour, education, economics, social policy and general legislation development, and environmental modification.

- As an educational tool - in curriculum design and to raise awareness and undertake social action.

  - [Source: ICF, WHO 2001]

* Well, and in fact of any of the international classification systems...
Classification of aphasias

Figure from: [emedicine.medscape.com]

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