Neurorehabilitation. Fundamentals

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Outline

- Definition of Neurorehabilitation
- International Classification of Functioning, Disability and Health (ICF)
- Neurological rehabilitation
- Physiological consequences of CNS damage

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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.

Rehabilitación

- **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
  - [Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

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.boots.com/a-to-z-guides/brain-damage-symptoms-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.]

Neurorehabilitation

- **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.]

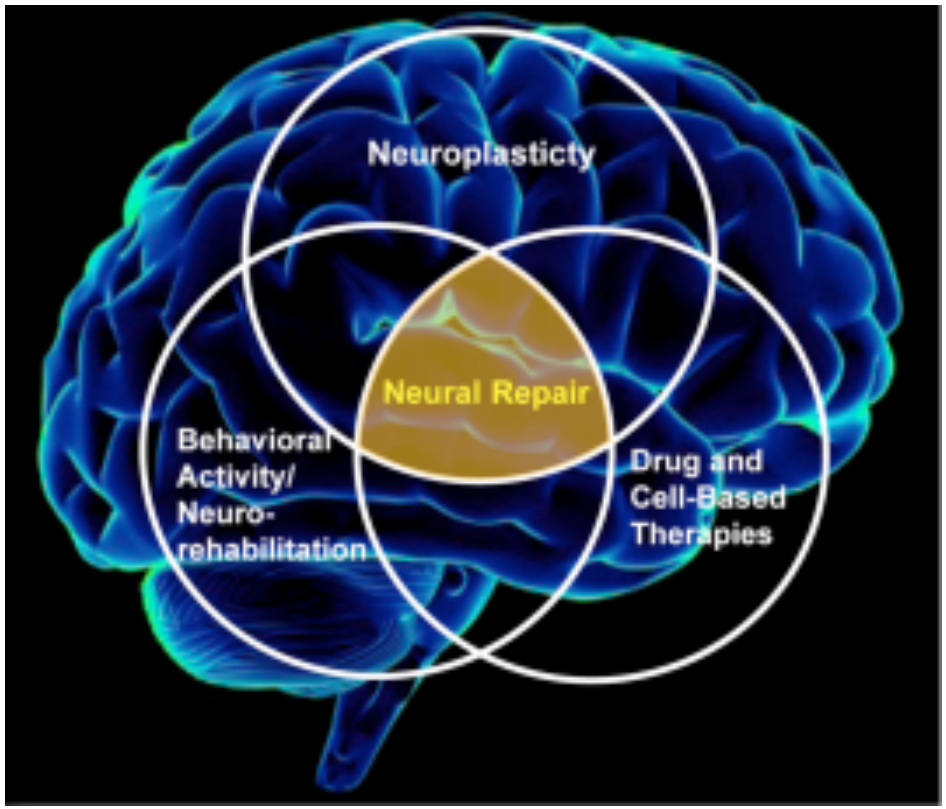

Figure from: [http://carmichaellab.neurology.ucla.edu/integrated-view-neural-repair-after-stroke]

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.

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.

Relation ICD and ICF

- 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).

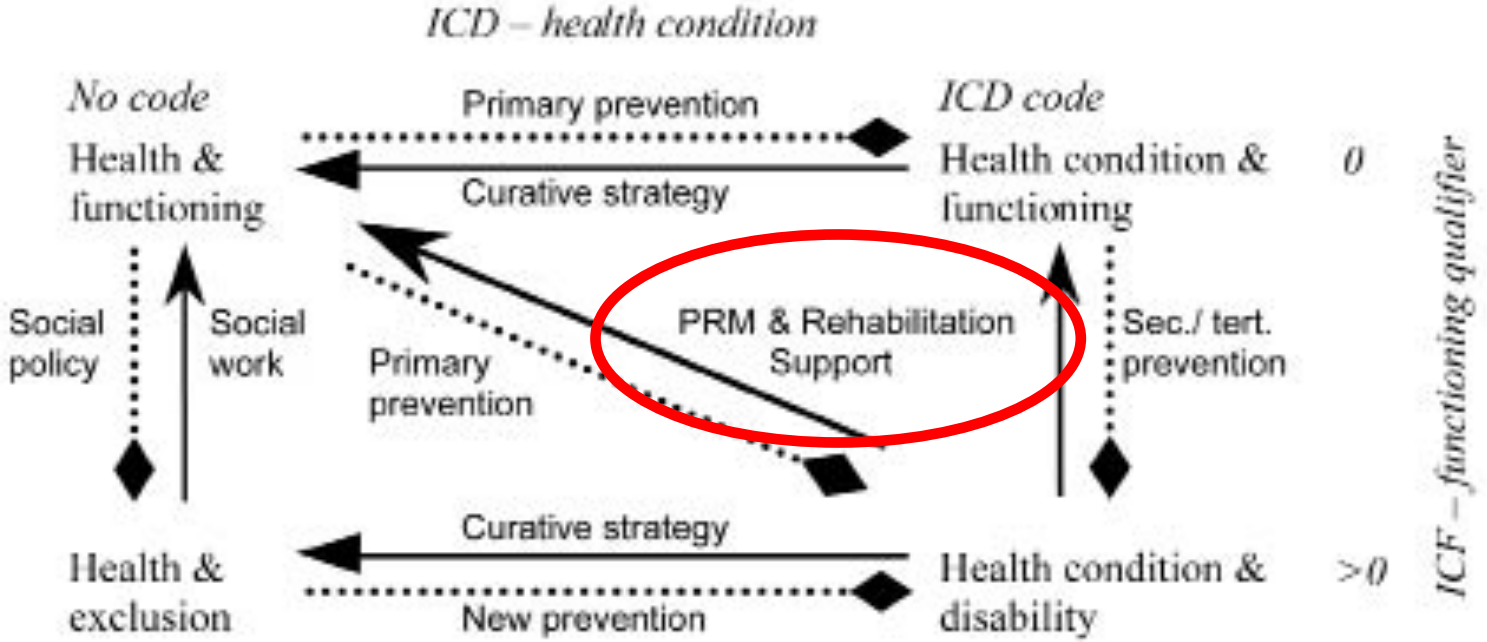

Figure from: [Reinhardt JD et al (2009) J Rehabil Med Preview 41: 810–822]

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[11]

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. a.k.a. Disability

Participation is involvement in a life situation. a.k.a. Handicap

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.

[Source: ICF, WHO 2001]

Relation ICIDH and ICF

- 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 (*supersedes?*) 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

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

WHO 1980.

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

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

WHO 1998.

[Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

Overview of ICF

	Part 1: Functioning and Disability		Part 2: Contextual Factors	
Components	**Body Functions and Structures**	**Activities and Participation**	**Environmental Factors**	**Personal Factors**
Domains	Body functions Body structures	Life areas (tasks, actions)	External influences on functioning and disability	Internal influences on functioning and disability
Constructs	Change in body functions (physiological) Change in body structures (anatomical)	Capacity Executing tasks in a standard environment Performance Executing tasks in the current environment	Facilitating or hindering impact of features of the physical, social, and attitudinal world	Impact of attributes of the person
Positive aspect	Functional and structural integrity	Activities Participation	Facilitators	not applicable
	Functioning			
Negative aspect	Impairment	Activity limitation Participation restriction	Barriers / hindrances	not applicable
	Disability			

[Source: ICF, WHO 2001]

ICF first level classification*

Body functions

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

Body structures

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

Activities and participation

Chapter 1	Learning and applying knowledge
Chapter 2	General tasks and demands
Chapter 3	Communication
Chapter 4	Mobility
Chapter 5	Self-care
Chapter 6	Domestic life
Chapter 7	Interpersonal interactions and relationships
Chapter 8	Major life areas
Chapter 9	Community, social and civic life

Environmental factors

Chapter 1	Products and technology
Chapter 2	Natural environment and human-made changes to environment
Chapter 3	Support and relationships
Chapter 4	Attitudes
Chapter 5	Services, systems and policies

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

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 gesturing 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

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NEUROLOGICAL REHABILITATION

ICF key concepts

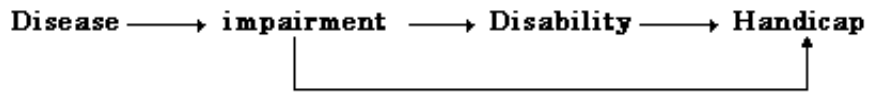
- **Impairments**: Description. Implies nothing about consequence.
  - Examples: Hemiparesis, sensory loss
- **Activity** / **Disability**: Limitation.Functional consequence of impairment.
  - Examples: Inability to walk, dressing, etc
- **Participation** / **Handicap**: Restriction. Social context of the disability. Has implications for rehabilitation.
  - Example: Prevention to enrole in armed forces, maintaining a job, doing sports, etc

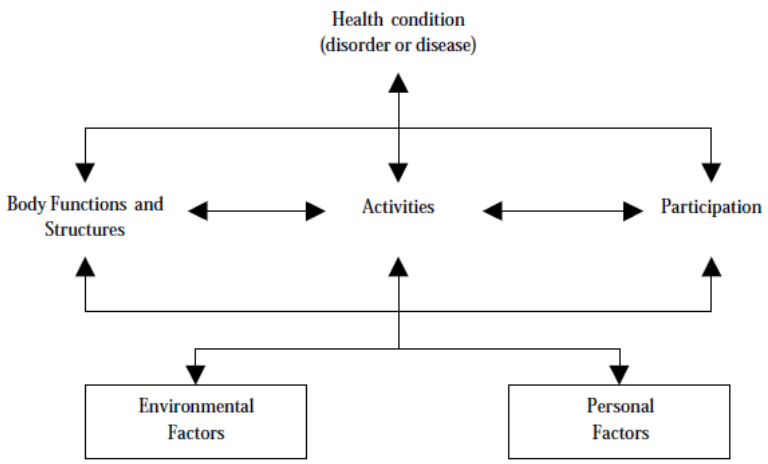
[Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

ICF functioning model

Evolution

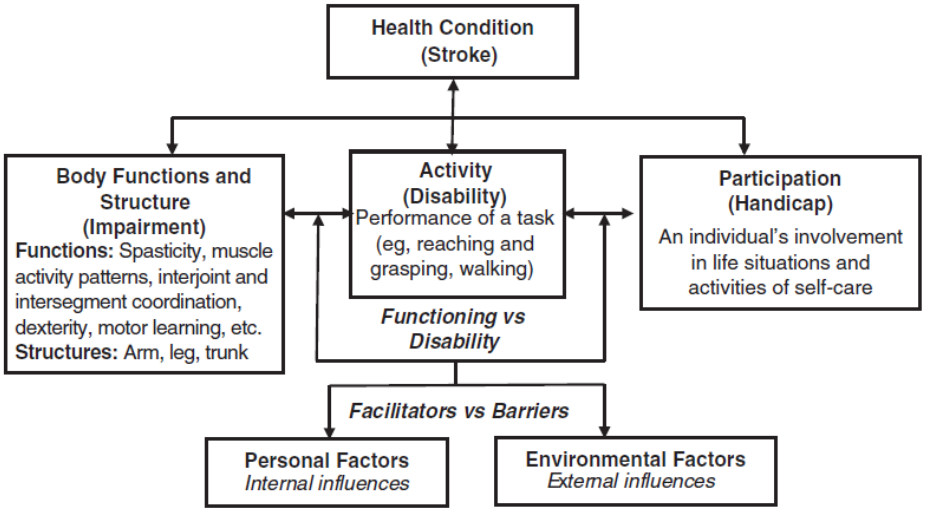
Figure 1 : ICIDH MODEL (WHO 1980)





Example

Figure 1
World Health Organization International Classification of Functioning Model



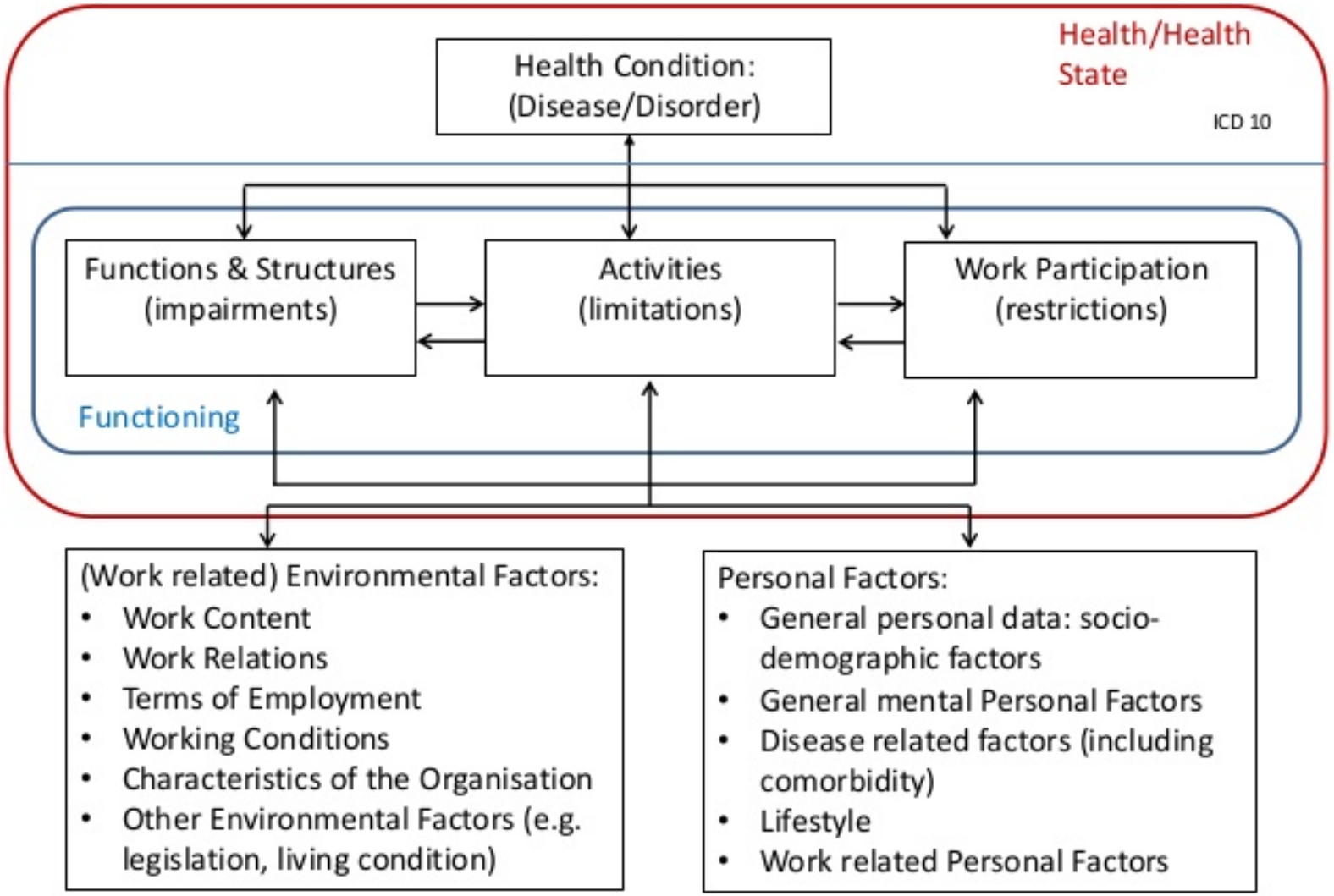
Source: [ICF, WHO 2001]

Source: [Levin MF (2009) NNR, 23(4):313-319]

ICF functioning model

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

[Heerkens et al: Disabil Rehabil 26 (17), 2004; WHO-FIC Annual Network Meeting, Brazil 2012], [Geyh et al: Disabil Rehabil.33(13-14) 2011]



ICF functioning model: Example

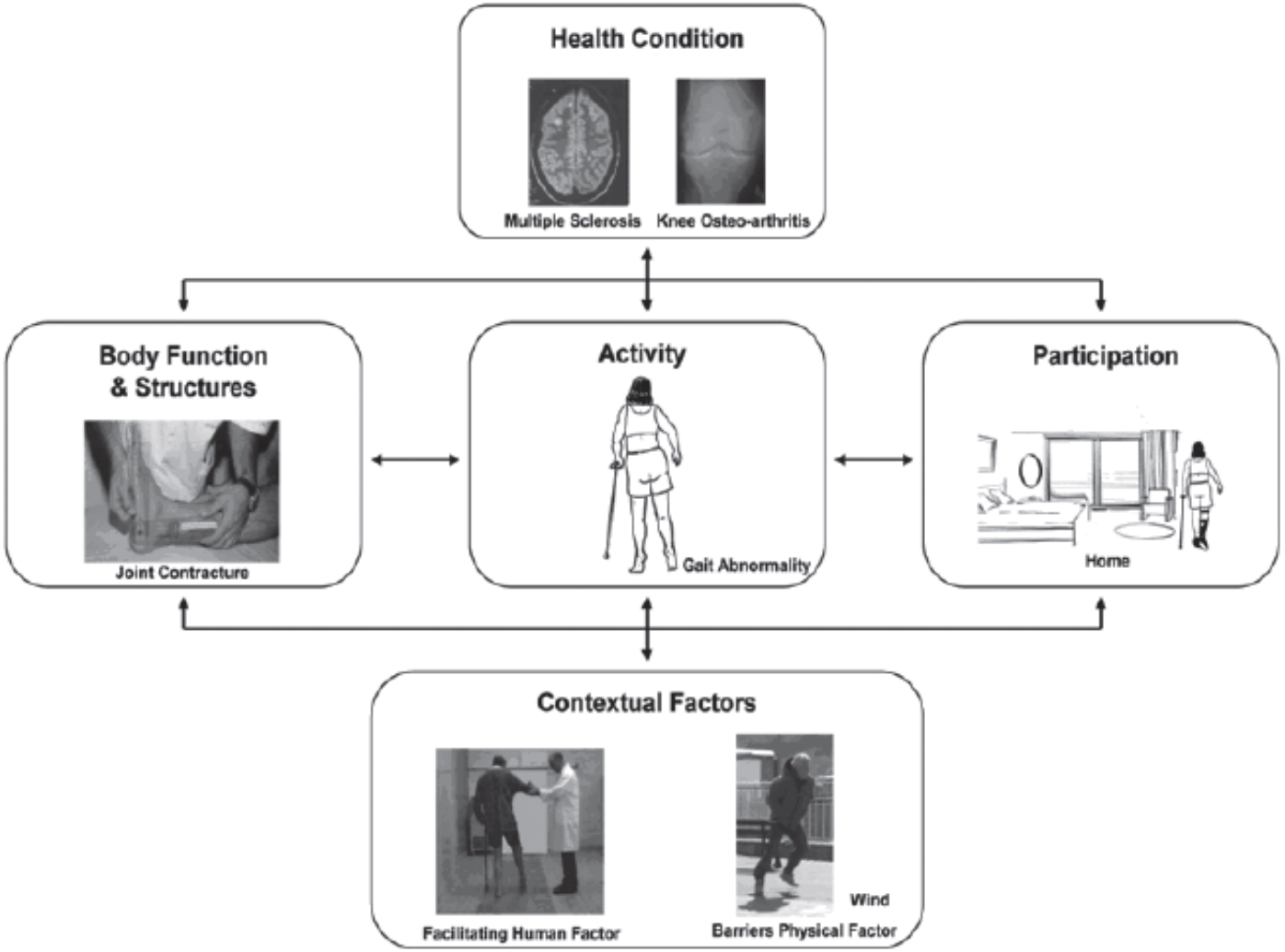


Figure from: [Bensoussan L et al (2008) J Rehabil Med 40:497-507]

ICF functioning model: The case of stroke

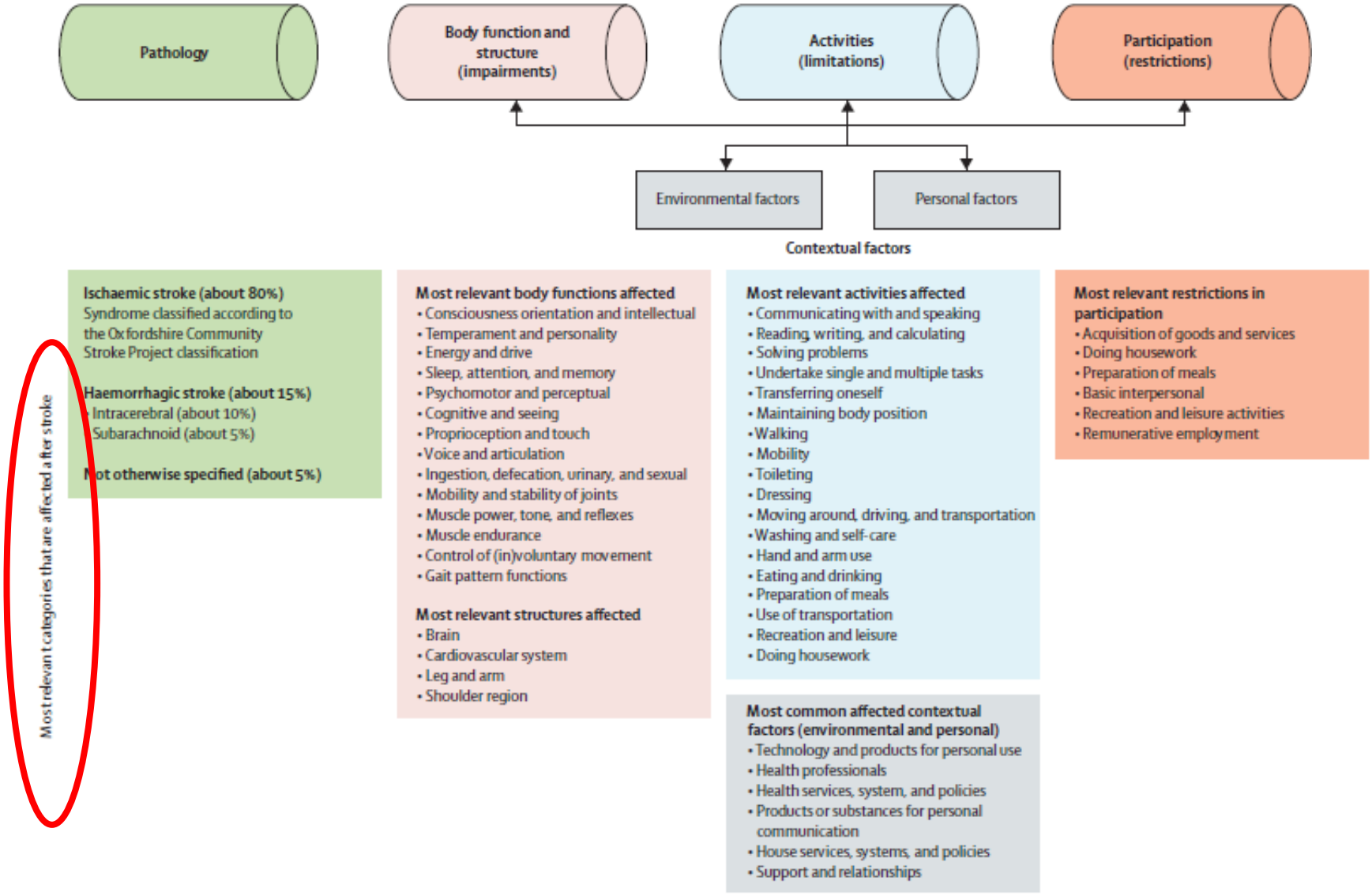


Figure from: [Langhorne P et al (2011) Lancet 377:1693-702]

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

[Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

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

[Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

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)

[Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

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.

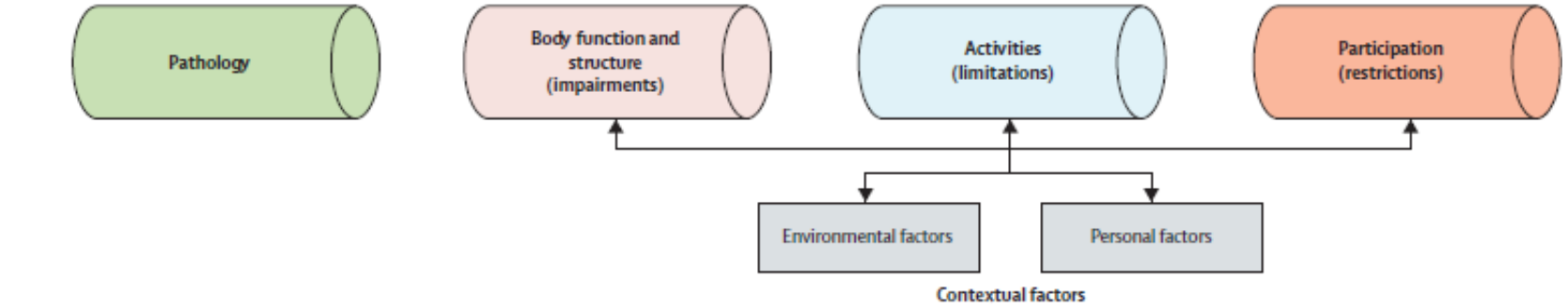
[Barnes MP (2003) JNNP, 74(Suppl IV):iv3-iv7]

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



Classification of commonly used scales for outcome

Diagnostics
- CT or MRI scan (with or without contrast)
- Doppler
- Electrocardiogram

Examinations
- History from patient and family
- Clinical examination
- Fundoscopic examination
- Auscultation
- Blood analysis (including pressure)

Body structure (impairments)

Neurological scales
- Glasgow coma scale
- Mini mental state examination
- National Institutes of Health stroke scale
- Scandinavian stroke scale
- Canadian neurological scale

Other scales used by the stroke team
- Cumulative illness rating scale
- Bells and star cancellation tests
- Western aphasia battery
- Ontario Society of Occupation Therapists perceptual evaluation
- Medical Research Council
- Motricity index of arm and leg
- Fugl-Meyer motor assessment
- Motor assessment scale
- Fatigue severity scale
- Hospital anxiety and depression scale
- Hamilton rating scale for depression
- Cambridge cognition examination

Activity (disability)

Global ADL-scales
- Barthel index
- Functional independence measure
- Frenchay activities index
- (modified) Rankin scale

Other scales used by the stroke team
- Trunk control test
- Timed up-and-go
- Berg balance scale
- Rivermead mobility index
- 5 or 10 metre gait speed
- 2 or 6 minute walk test
- Stair climbing test
- Frenchay arm test
- Action research arm test
- Wolf motor function test
- Toronto bed-side swallowing screening test
- American Speech-Language-Hearing Association functional assessment of communication skills

Contextual factors
- Caregiver strain index
- Family assessment device

Participation (handicap)
- Euroqol-5D
- Frenchay activities index
- Nottingham extended activities of daily living
- Nottingham health profile
- General health questionnaire
- Stroke impact profile (stroke adapted version)
- Medical outcome study short form 36
- Stroke-specific quality of life

These complement each other; Scales of imapairment cannot detect compensatory movements. Scales of disabilities cannot differentiate improvements on impairment. [Kwakkel et al (2004) Rest. Neurol. NeuroSci 22:281-299]

Figure from: [Langhorne P et al (2011) Lancet 377:1693-702]

Fugl-Meyer assesment of motor impairment

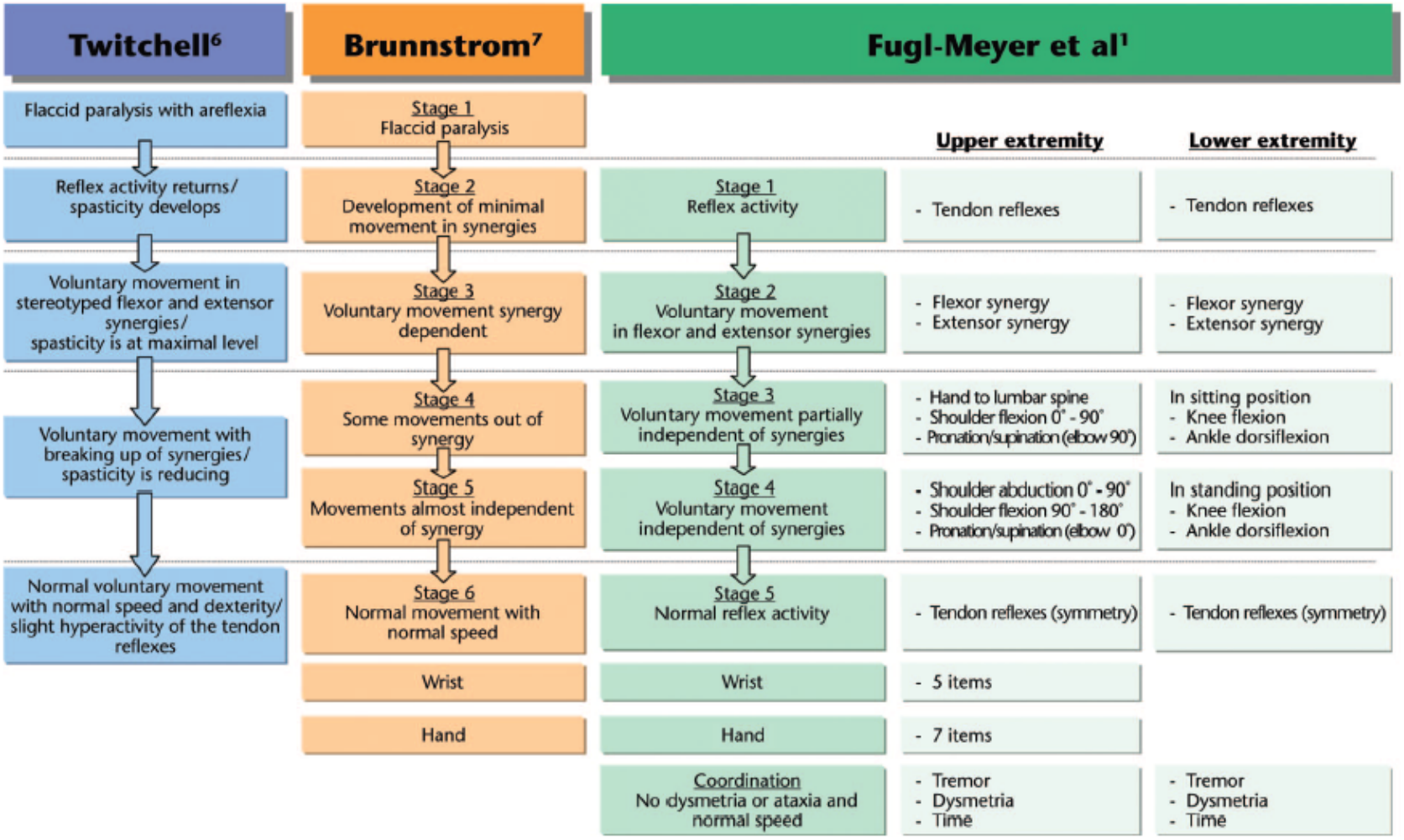
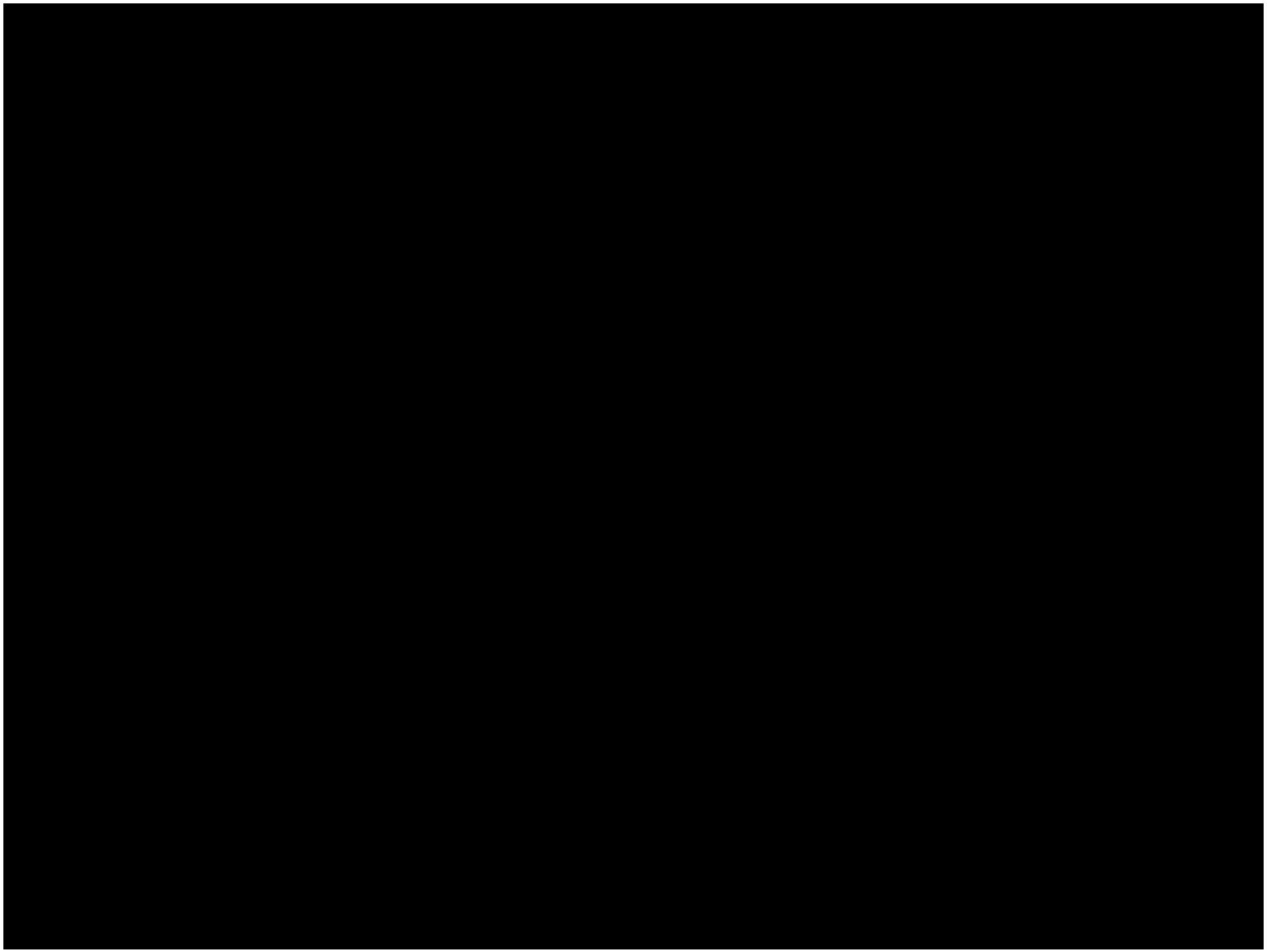


Figure 1.
Comparison of sequence of stepwise recovery described by Twitchell[6] and Brunnstrom[7] with the stages and scale items used by Fugl-Meyer et al.[1]

Figure from: [Crow and Harmeling-van der Wel (2008) Phys. Ther. 88:1554-1567]

Fugl-Meyer assesment of motor impairment



Total time: 3:47

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

Components of neurorehabilitation

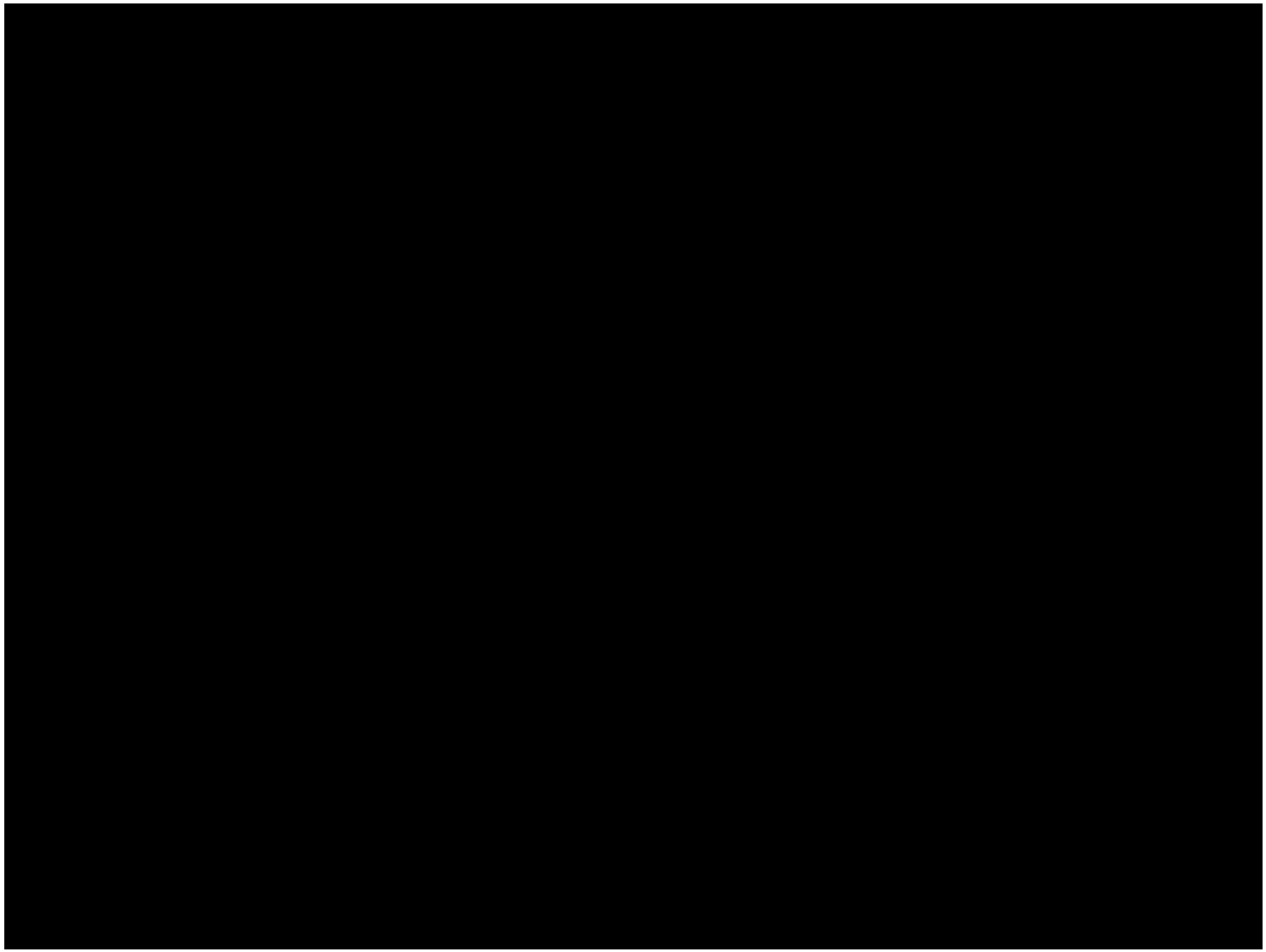
- Physical rehabilitation
  - Concerned with physical impairments and movement dysfunctions
  - Aims to increase mobility and function
- Cognitive rehabilitation
  - Concerned with cognition impairments
  - Submodalities
    - Aphasia rehabilitation: centered on language disorders
- Occupational therapy:
  - Focus on evaluating and improving a persons 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

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

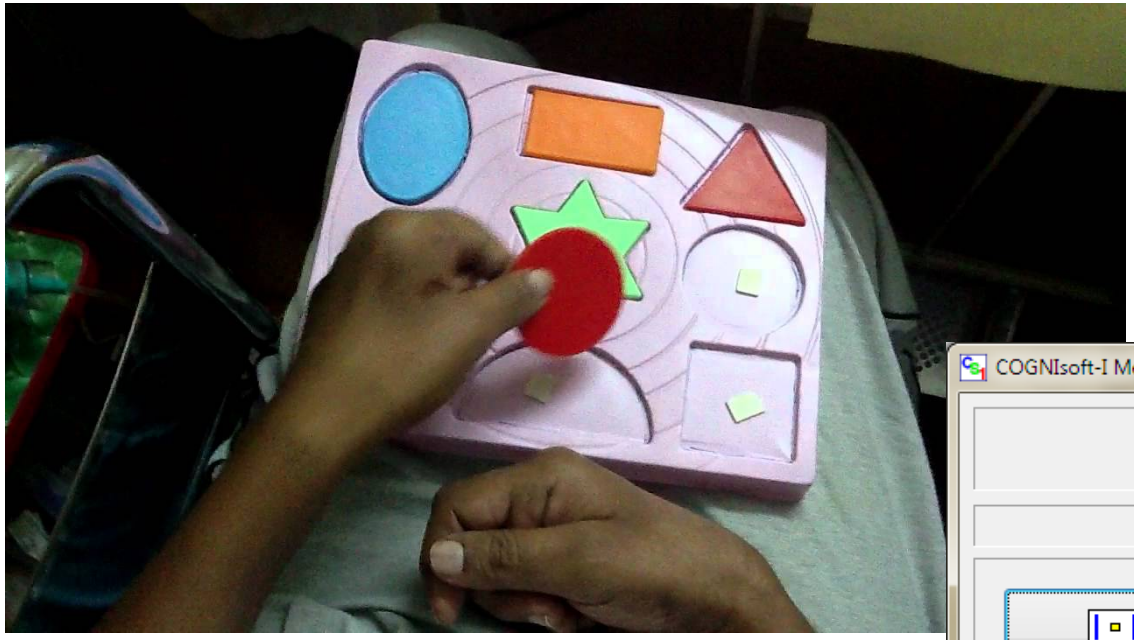


Figure from: Snapshot from YouTube video [https://www.youtube.com/watch?v=-qpMi_2VXvc/]

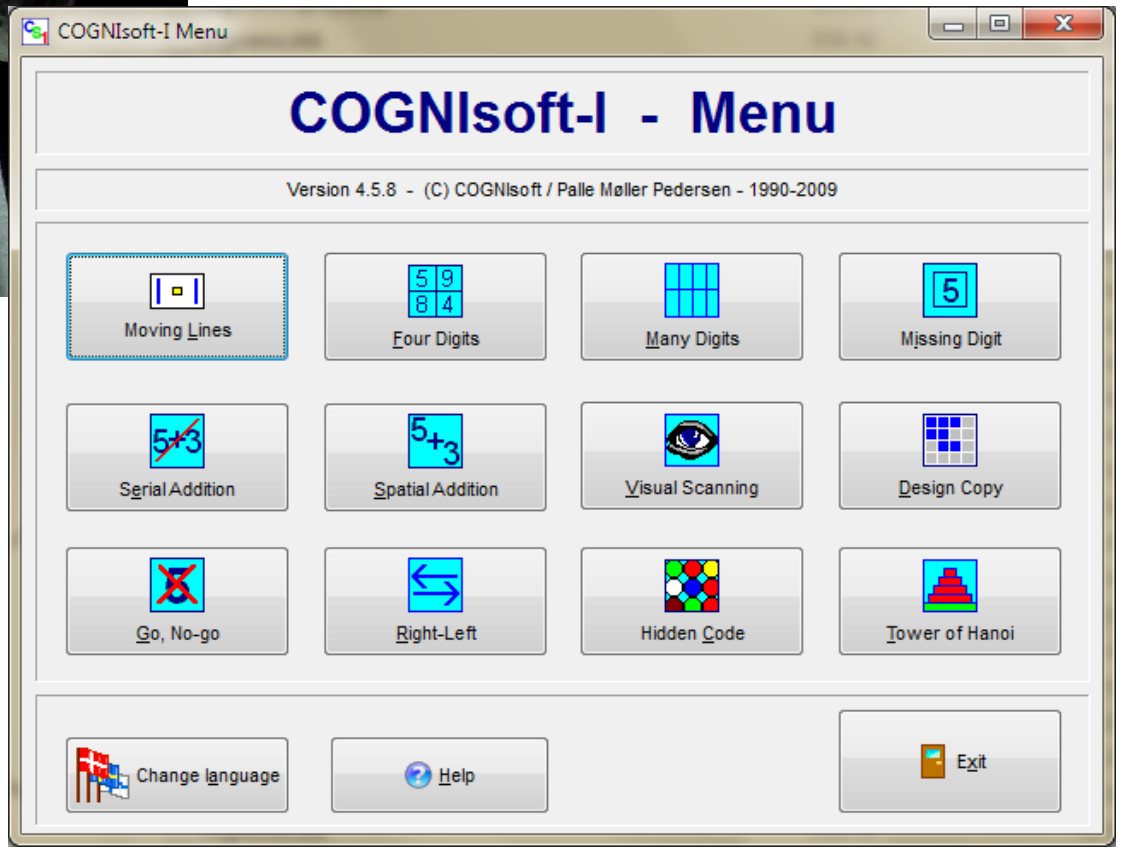


Figure from: [http://www.cognisoft.info/cognisoft-i.html]

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PHYSIOLOGICAL CONSEQUENCES OF CNS DAMAGE

Neurorehabilitation

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

Example of damage caused by a stroke

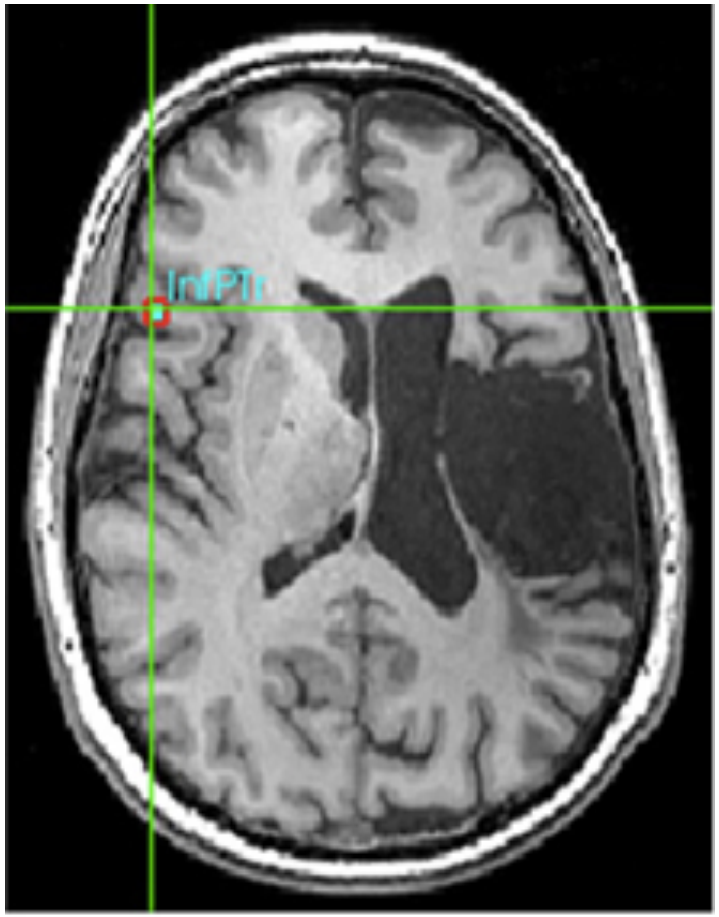


Figure from: [Shah et al 2013, Front. Hum. NeuroSci, 7:888]

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.

  - Source: [Horner and Gage (2000) Nature 407:963-970]

Neurorehabilitation

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

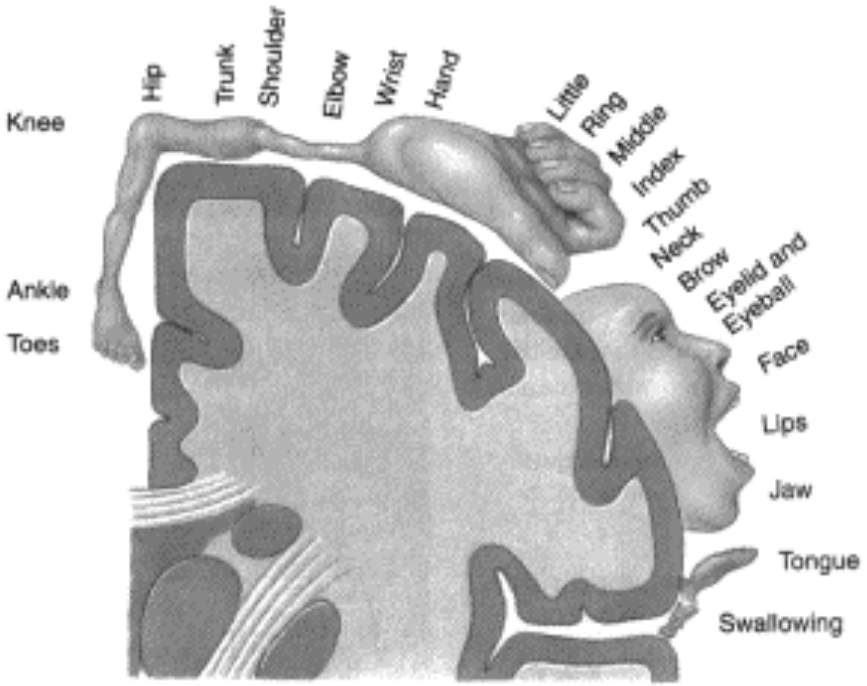


Figure from: [thebigview.com]

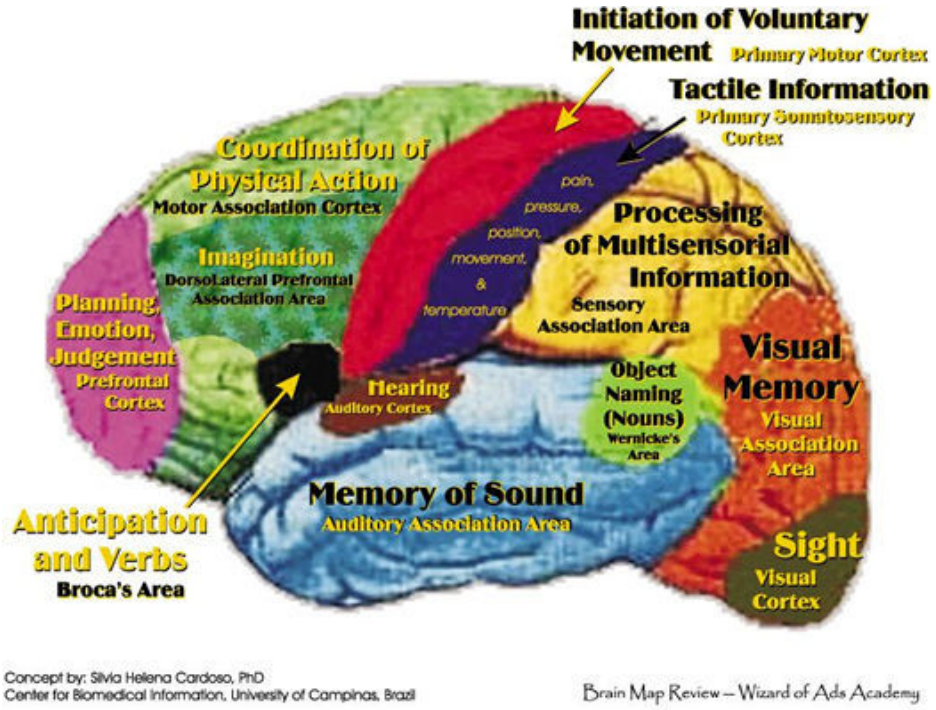


Figure from: [wizardsofads.com.au]

CNS injury

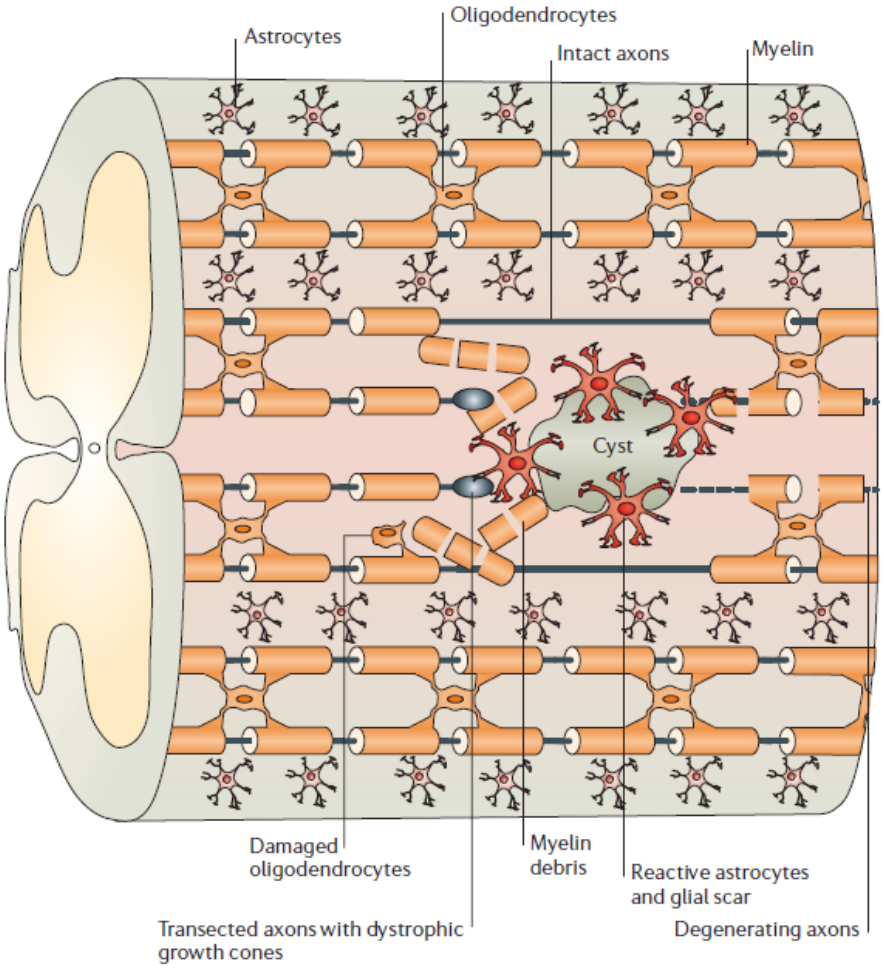


Figure 1 | **Schematic representation of the CNS injury site.** Injury to the adult CNS often results in the transection of nerve fibres and damage to surrounding tissues. The distal ends of the severed axons form characteristic dystrophic growth cones that are exposed to the damaged glial environment[4]. During the early phase of injury, myelin-associated inhibitors from intact oligodendrocytes and myelin debris can restrict axon regrowth[7–9]. Recruitment of inflammatory cells and reactive astrocytes over time leads to the formation of a glial scar, often accompanied by a fluid-filled cyst[10]. This scarring process is associated with the increased release of chondroitin sulphate proteoglycans, which can further limit regeneration[43]. 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

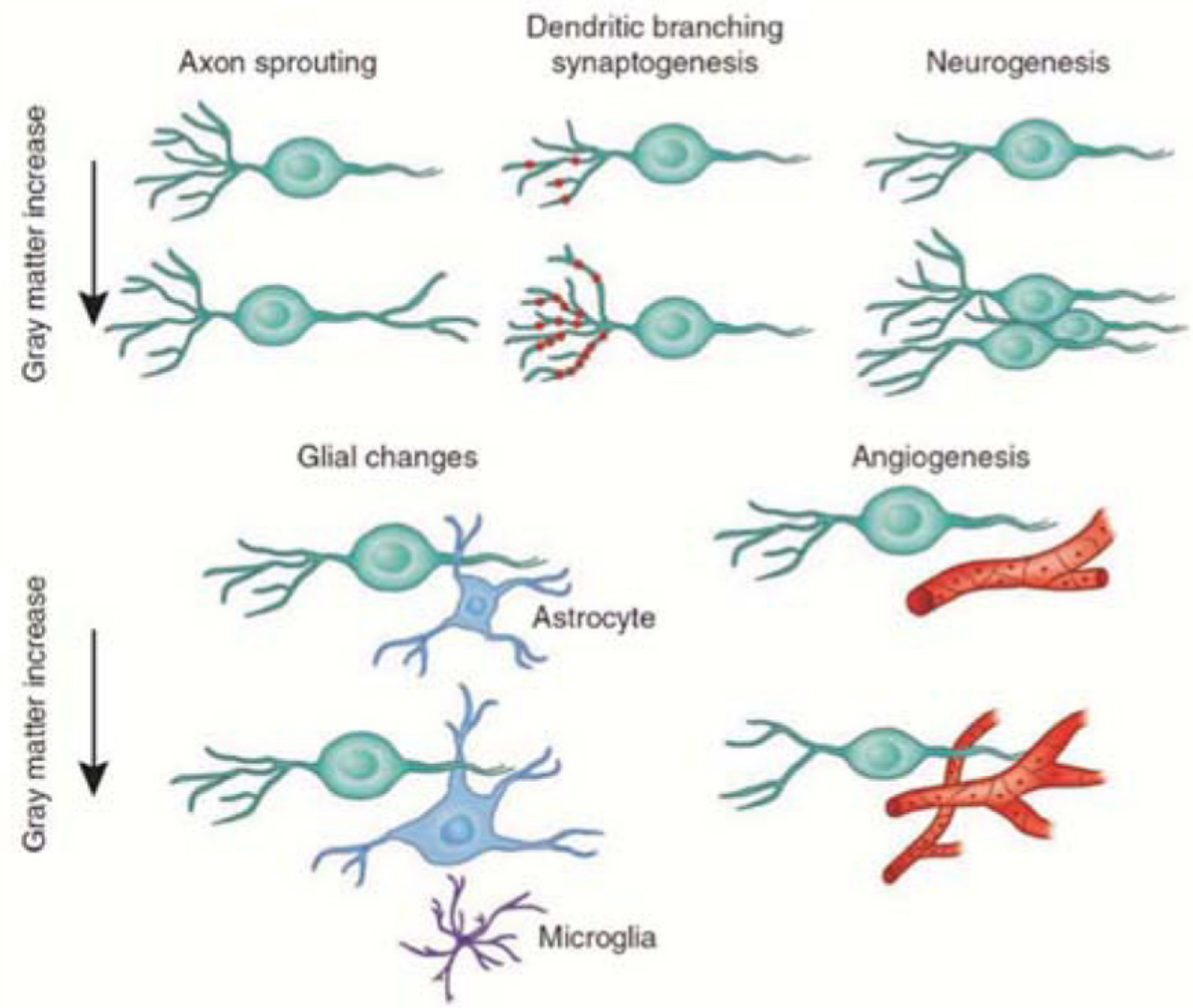
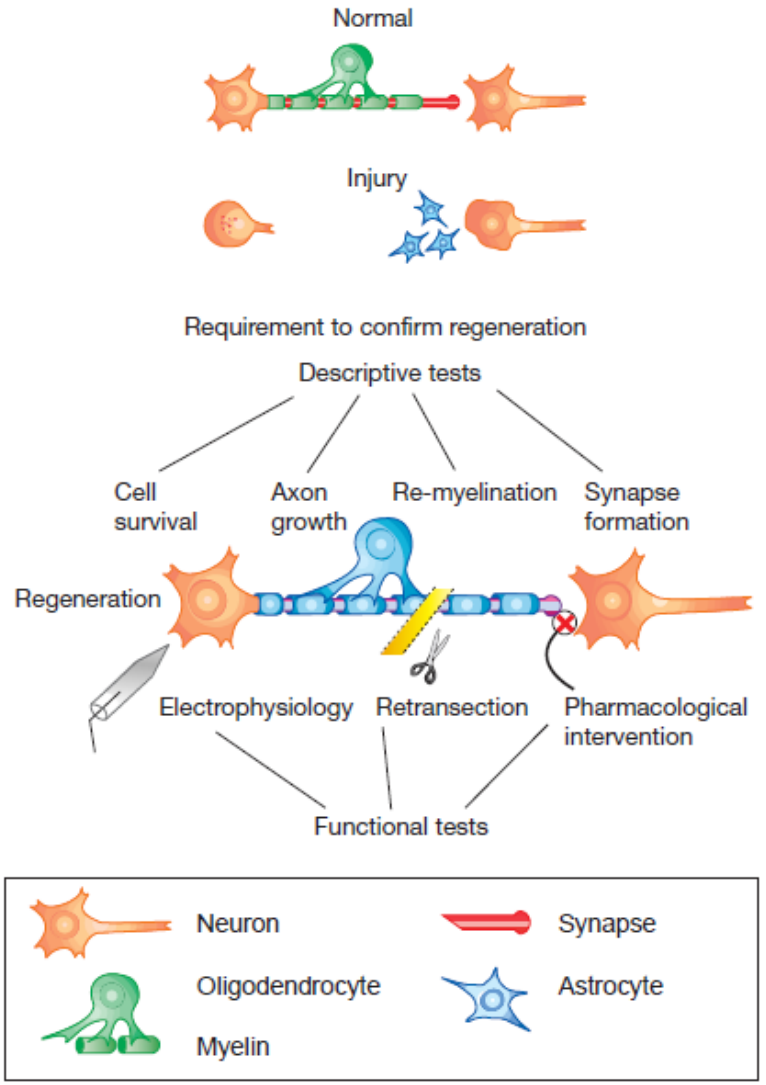


Figure from: [Royet et al (2013) Front Psych 4:928]

Functional regeneration

- Steps to functional regeneration.
  - Several criteria need to be met before functional regeneration can be validated including
    - Cell survival
    - Axon growth
    - Re-mylination
    - 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, retransection) is important to determine its role in any reported functional recovery.



- Source: [Horner and Gage (2000) Nature 407:963-970]

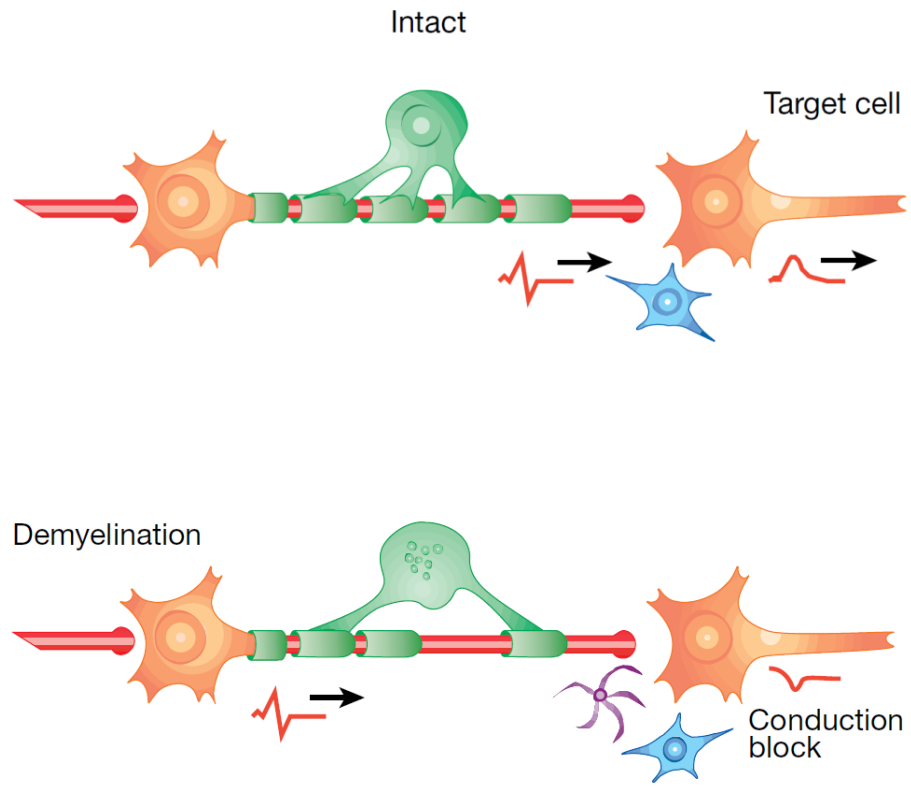
Consequences of neuronal injury

- 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.
  - Source: [Horner and Gage (2000) Nature 407:963-970]

Consequences of neuronal injury

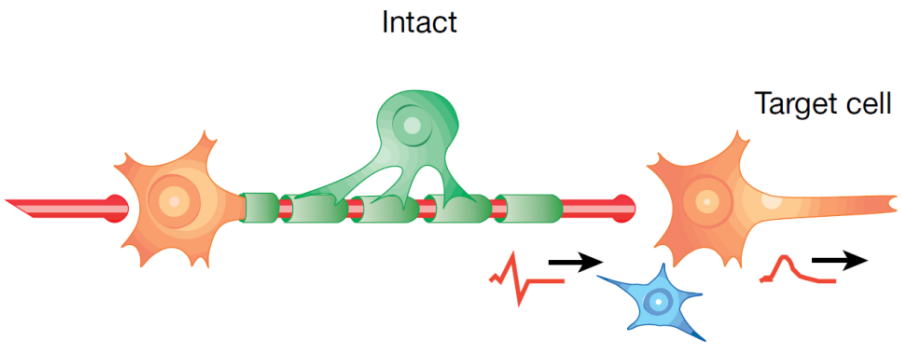
- **Demyelination**.
  - A demyelinated axon may maintain both its afferent and efferent connections but, due to a loss of myelination, poor or failed conduction results.

- Source: [Horner and Gage (2000) Nature 407:963-970]

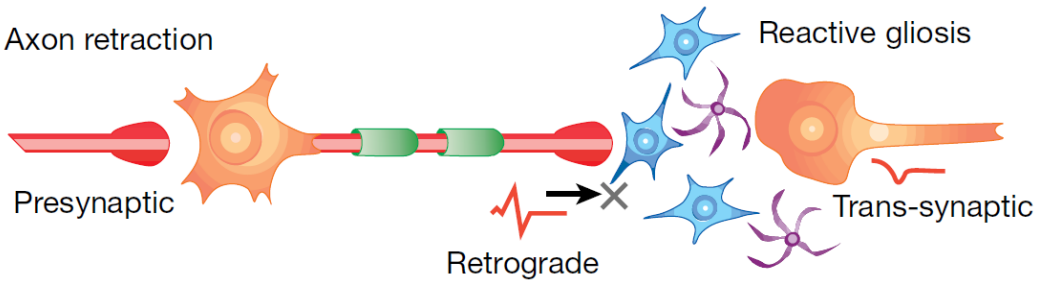


Consequences of neuronal injury

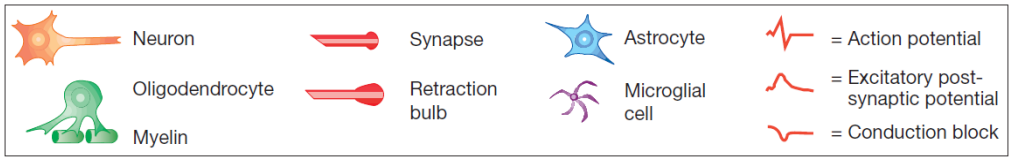
- **Axonal retraction**.
  - Retraction: Selective elimination of axons, dendrites, axon and dendrite branches, and synapses, without loss of the parent neurons is a necessary mechanism to generate precise connectivity patterns [Luo and O'Leary (2005) Annu Rev Neurosci. 28:127-56]



  - 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.



- Source: [Horner and Gage (2000) Nature 407:963-970]

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.

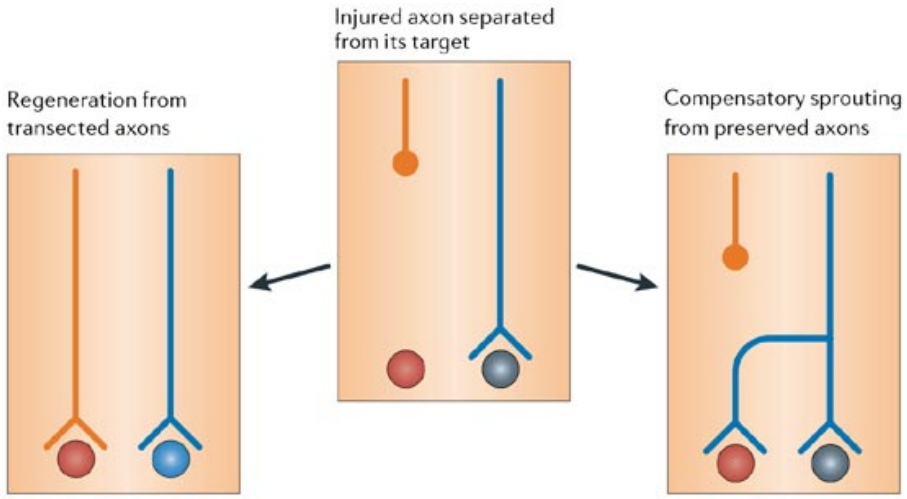
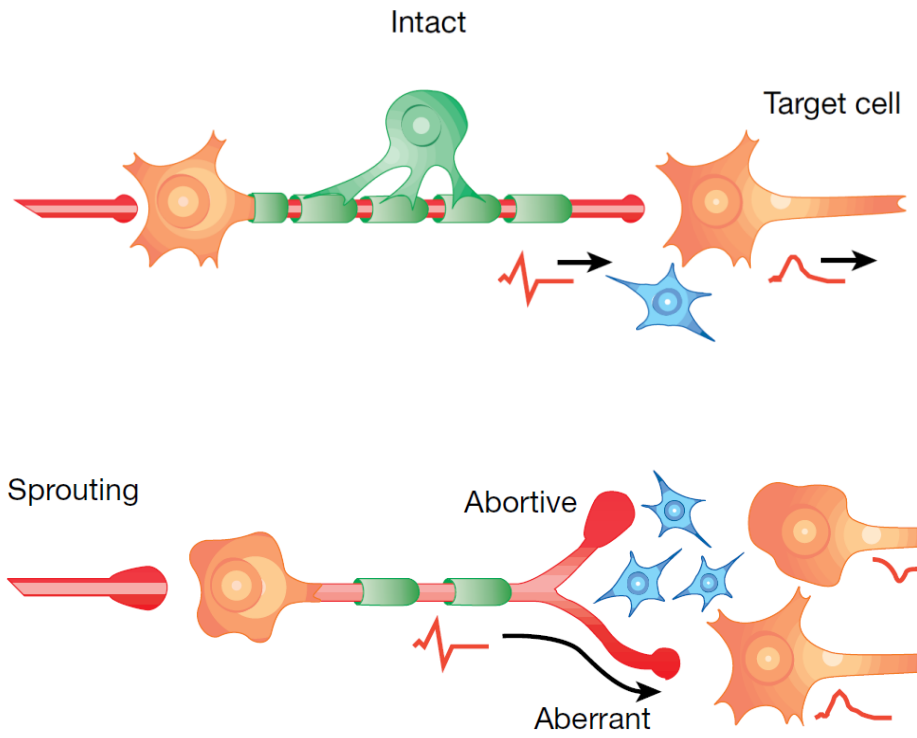


Figure from: [Yiu and He (2006) Nat. Rev. NeuroSci, 7:617-627]

Consequences of neuronal injury

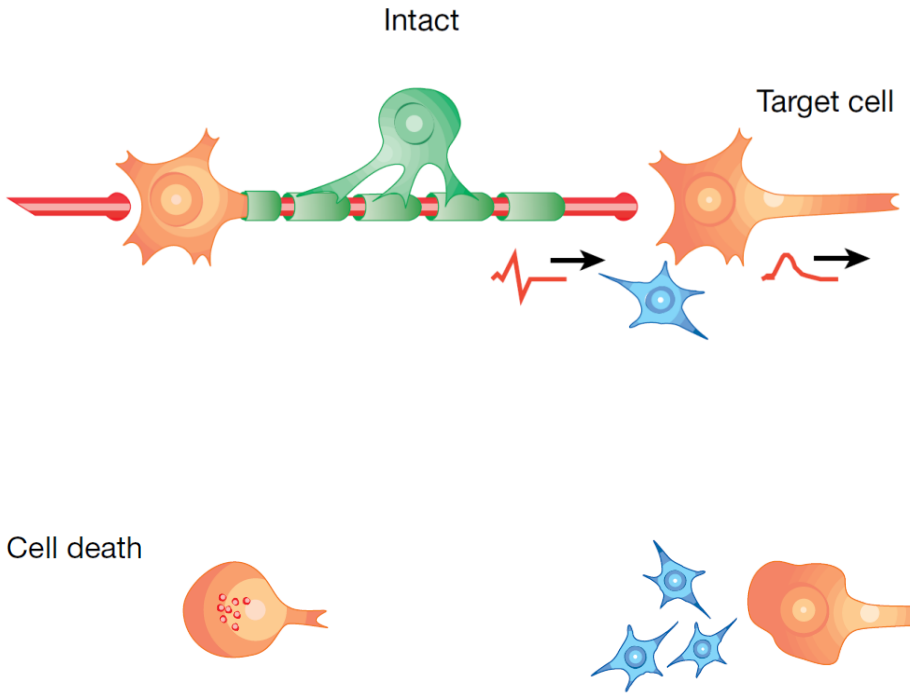
- **Sprouting**.
  - It is abortive when a sprouting axon encounters an inhibitory matrix or scar, loss of neurotrophin support, or the presence of continuing inflammation or toxicity.
  - Aberrant sprouting can occur when an axon reconnects to an inappropriate target.
    - Synaptic conduction is restored 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.

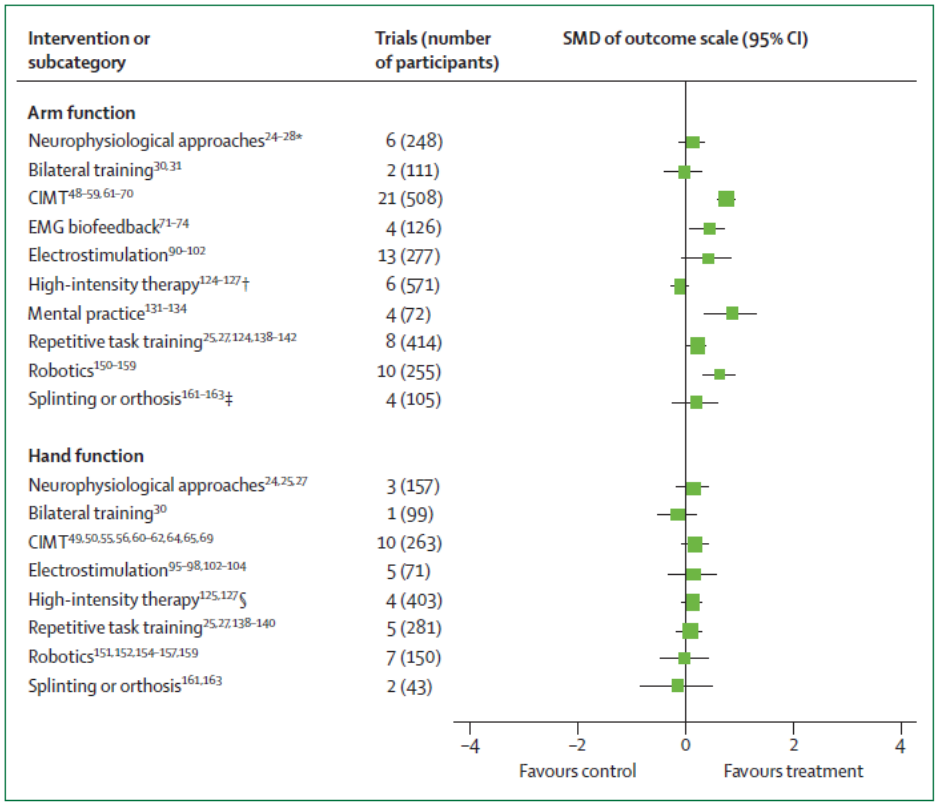


Figure 2: **Interventions to improve upper-limb motor recovery after stroke**
This figure summarises the results for upper-limb interventions targeting the recovery of arm or hand function, and shows the intervention category, number of trials (participants recruited) plus the SMD and 95% CI for the 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 Fugyl-Meyer scale. The most common measures of hand function were various peg tests and the hand component of the action research arm test. CIMT=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]

Neurorehabilitation: Doing things right

- 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.

Intervention depends in timing

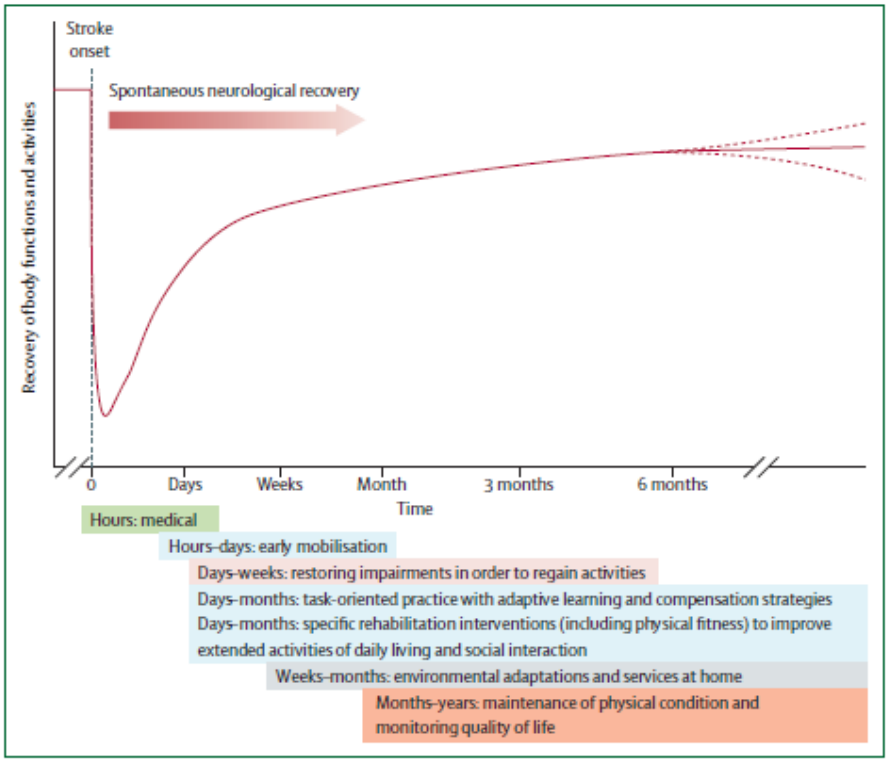


Figure 2: **Hypothetical pattern of recovery after stroke with timing of intervention strategies**
Colour coding of the intervention strategies matches the coding in figure 1.

Figure from: [Langhorne P et al (2011) Lancet 377:1693-702]

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.

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

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

Brain plasticity

- **Plasticity** is tha 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

[KolbB2010] Kolb, B., Muhammad, A., & Gibb, R., Searching for factors underlying cerebral plasticity in the normal and injured brain, Journal of Communication Disorders (2010), doi:10.1016/j.jcomdis.2011.04.007

Reorganization mechanisms and strategies

Reorganization mechanisms

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

Reorganization strategies

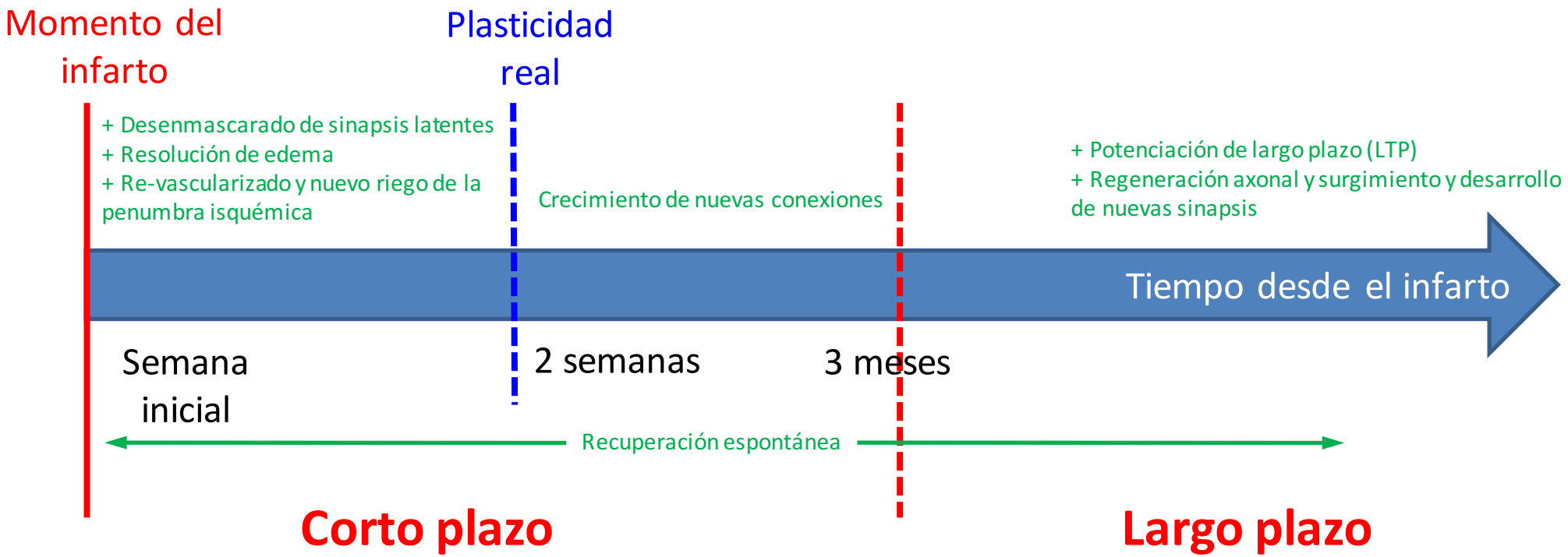
- Cortical representation
- Dictates *where* reorganization occurs

[KolbB2010] Kolb, B., Muhammad, A., & Gibb, R., Searching for factors underlying cerebral plasticity in the normal and injured brain, Journal of Communication Disorders (2010), doi:10.1016/j.jcomdis.2011.04.007

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



Reorganization strategies

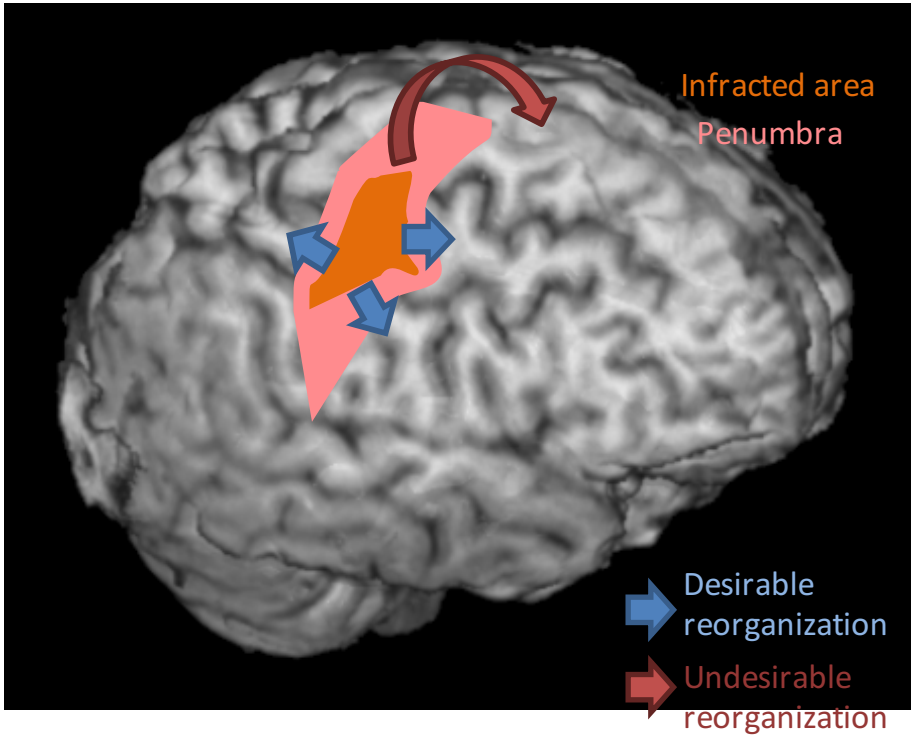
Table 2. Common functional reorganization strategies following stroke affecting the motor cortex

Reorganization strategy	Functional interpretation
Ipsilesional activation of M1[21,22]	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.
Contralesional activation of the M1[22,32]	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.
Bilateral recruiting of secondary motor areas (SMA, PM)[21,33-35]	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.)
Recruitment of nonmotor areas (PFC, PPC, ACC, and insula)[21,33,35,36]	May reflect cortical compensatory cognitive strategies. Lesser attenuation with time suggests recourse to normal behavior; compensatory strategies become less necessary as recovery progresses.
Recruitment of the cerebellum[27]	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.
Recruitment of the basal ganglia[33]	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.
Swerving of the CST[10]	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.

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.

Impact of plasticity in rehabilitation

- 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 benefitial 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).



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

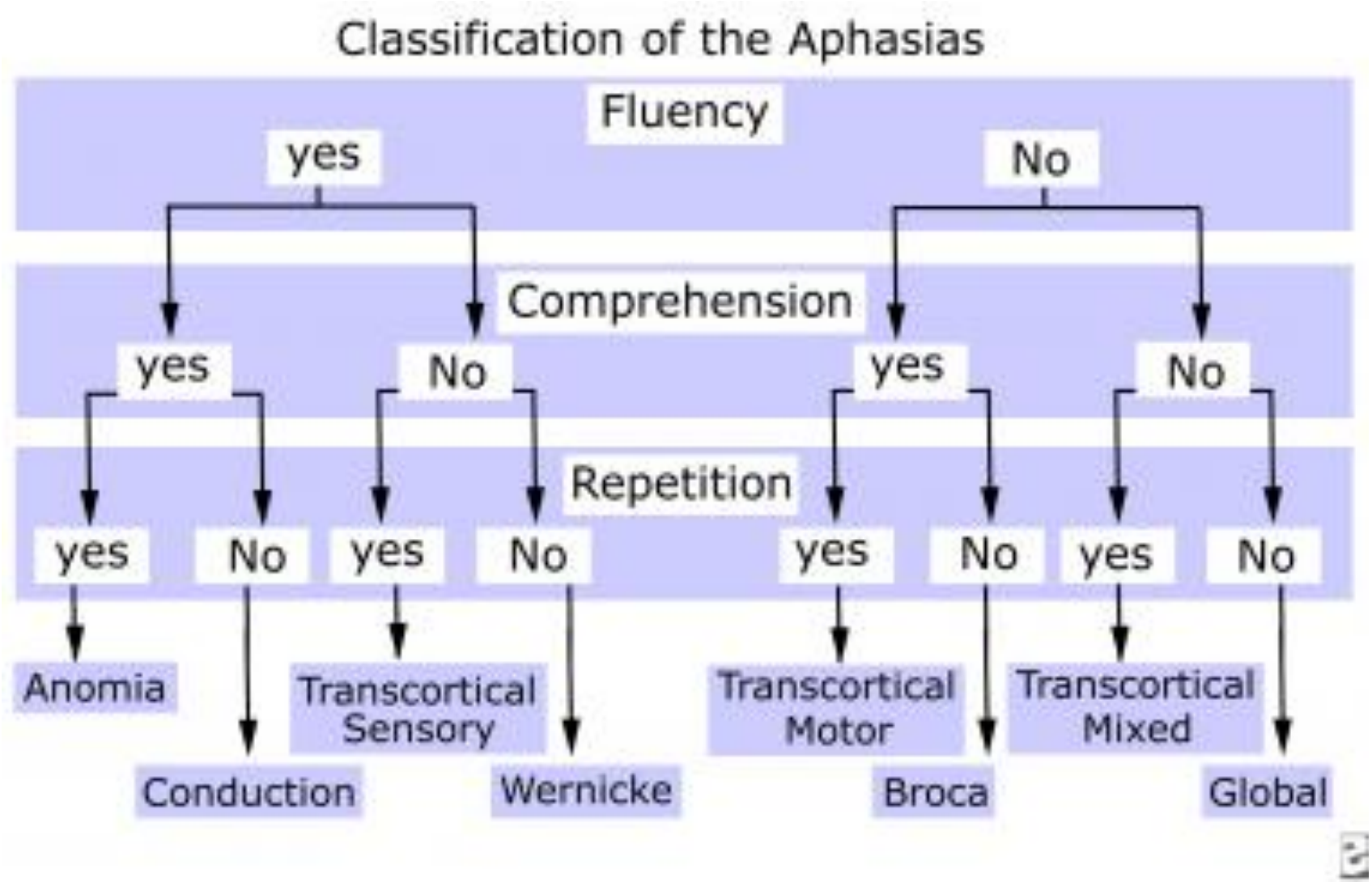


Figure from: [emedicine.medscape.com]