MOTOR CONTROL

MOTOR LEARNING

Basic Concepts

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Motor control

- Understanding the nature of movement
- Motor control theories
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Motor learning

- Stages of functional recovery
- Principle of Neural plasticity
- Motor learning theories
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MOTOR CONTROL CONCEPTS

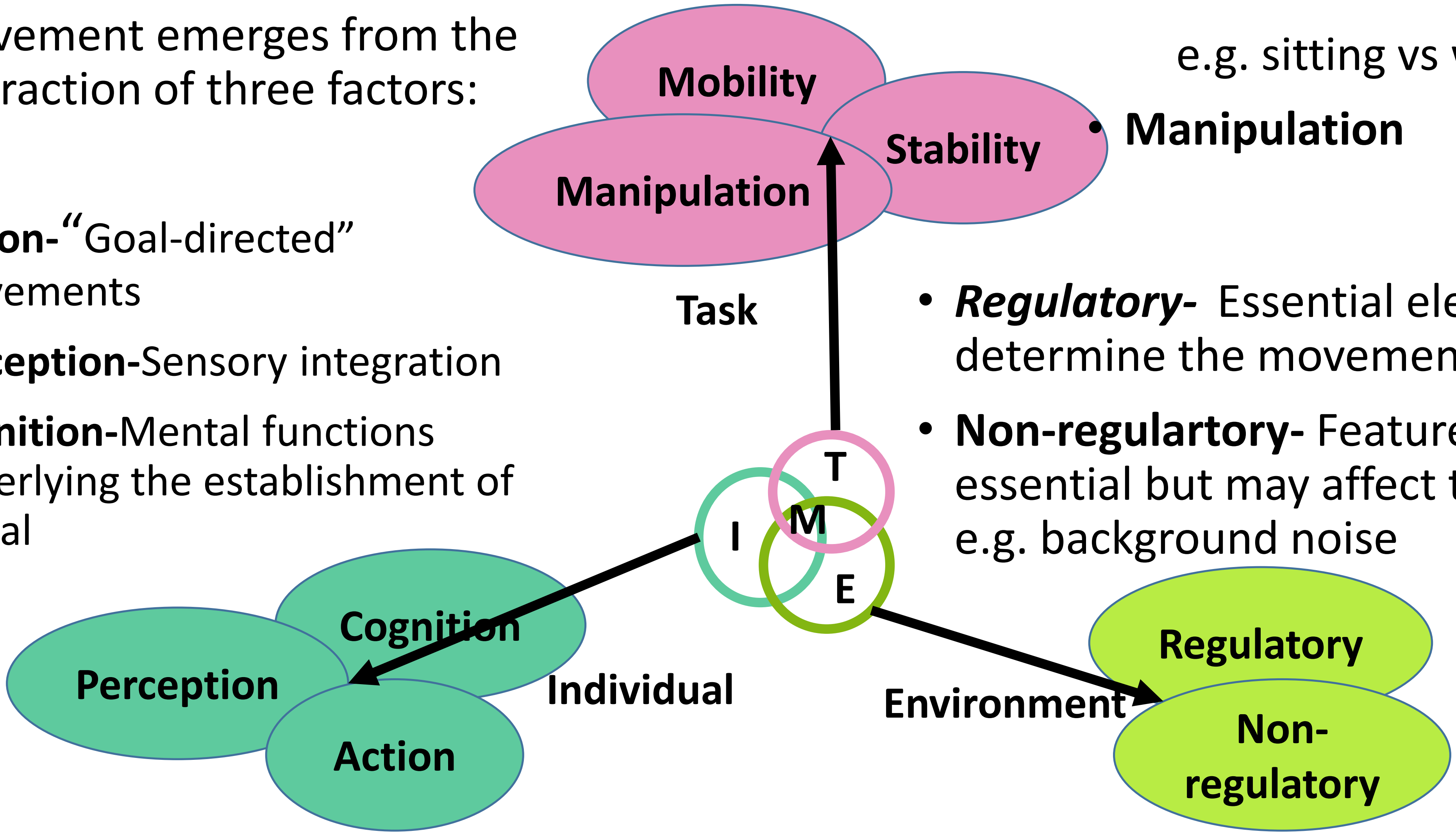
Motor control is defined as the ability to regulate the mechanisms essential to movement.

(Shumway-Cook A 1995)

Understanding the Nature of Movement

Movement emerges from the interaction of three factors:

- **Action-**“Goal-directed” movements
- **Perception-**Sensory integration
- **Cognition-**Mental functions underlying the establishment of a goal



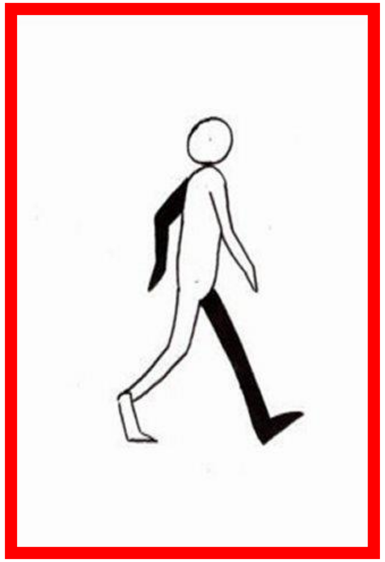
- **Stable vs mobility**,
  e.g. sitting vs walking
- **Manipulation**

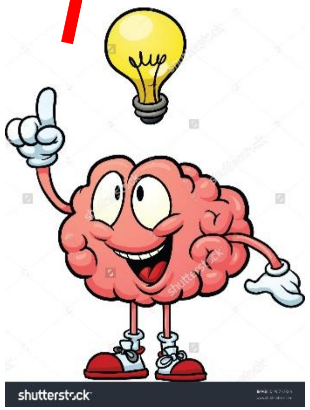
- ***Regulatory-*** Essential elements that determine the movement ,e.g. chair height
- **Non-regulartory-** Features that are not essential but may affect the performance, e.g. background noise

(Shumway-Cook A 1995)

Theories of Motor Control

- Reflex theory
- Hierarchical theory
- Motor programming theory
- Dynamic system theory
- Ecological theory



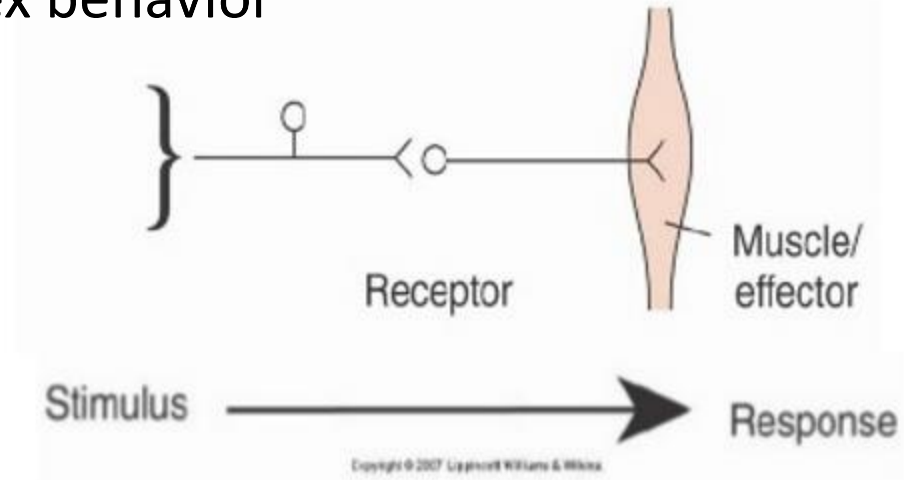


R.Cano-de-la-Cuerda et al, 2015

1. Reflex Theory by Sir Charles Sherrington (1906)

Reflexes were the building blocks of complex behavior

Basic structure of a reflex
a. Receptor
b. Conductor
c. Effector



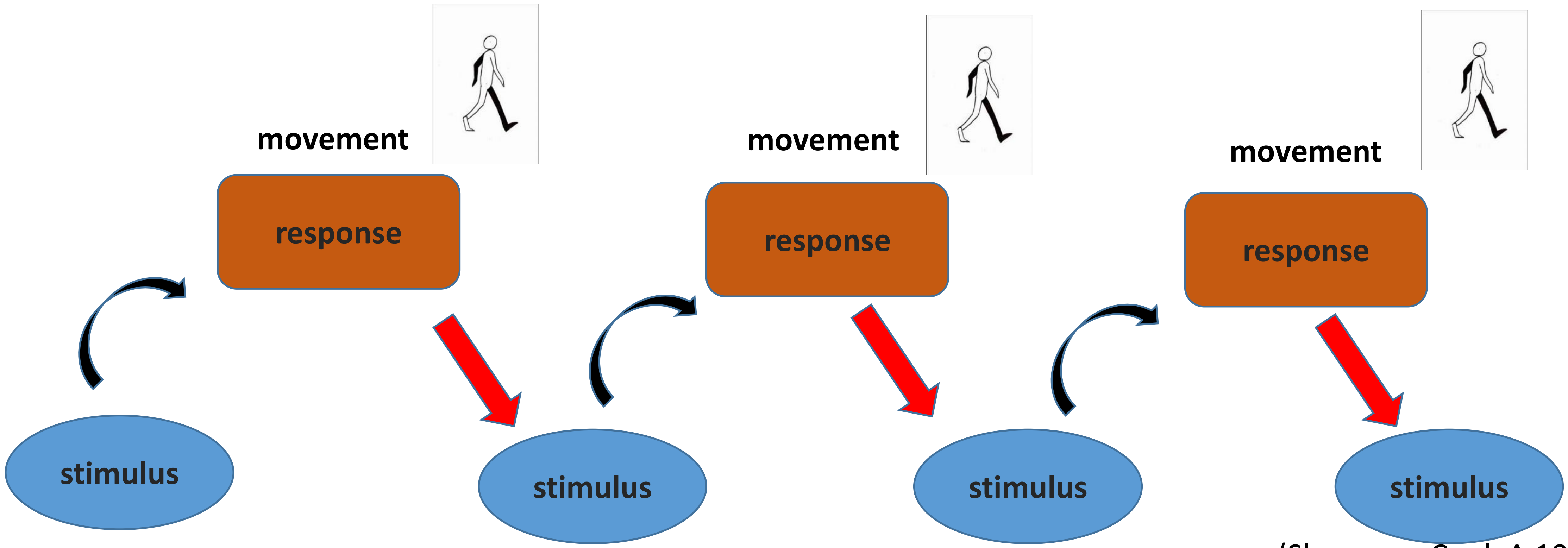
Afferent sensory inputs are necessary pre-requisite for efferent motor output.

(Shumway-Cook A 1995)

1. Reflex Theory (cont.)

Reflex chaining: complex movements are a sequence of reflexes elicited together.

A stimulus provokes a response, which is transformed into the stimulus of next response



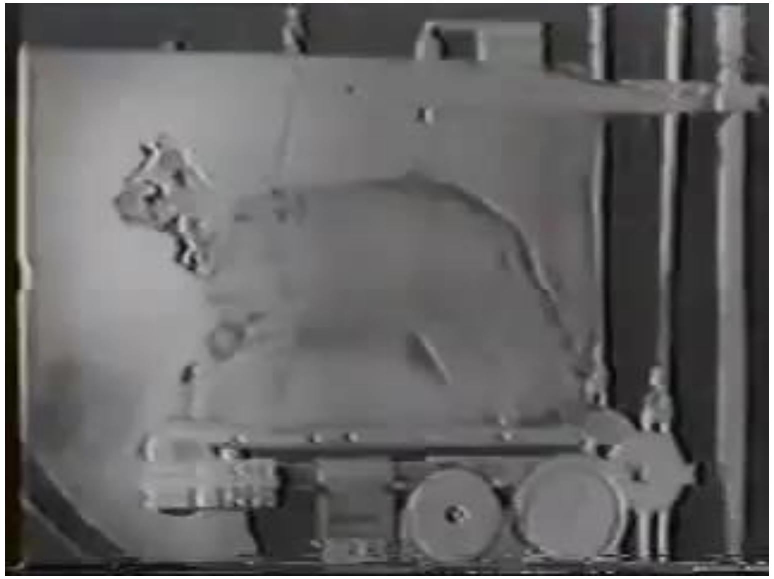
(Shumway-Cook A 1995)

1. Reflex Theory (cont.)

Limitations of reflex theory

Unable to explain

Spontaneous and voluntary movement (eg. heart beats, breathing, anaesthetic block arm can do dart throwing)



Movement can occur without sensory stimulus (eg. desensitized cat can walk)

(Shumway-Cook A 1995)

1. Reflex Theory (cont.)

Limitations of reflex theory

Unable to explain

Fast sequential movement (eg. typing or boxing- movement was 40 ms)

(not sufficient time to generate error, detect error, determine correction, initiate correction and correct movement before rapid movement is completed)

A single stimulus can trigger various response (reflex can be modulated) (eg. pull the child in fire)

Novel movement can be carried out. (eg. violinist learned rules for playing the piece and apply them to new situation such as cello)

(Shumway-Cook A 1995)

1. Reflex Theory (cont.)

Clinical implications

- Can imply clinically in retraining motor control by enhancing or reducing the effect of various reflexes during motor tasks

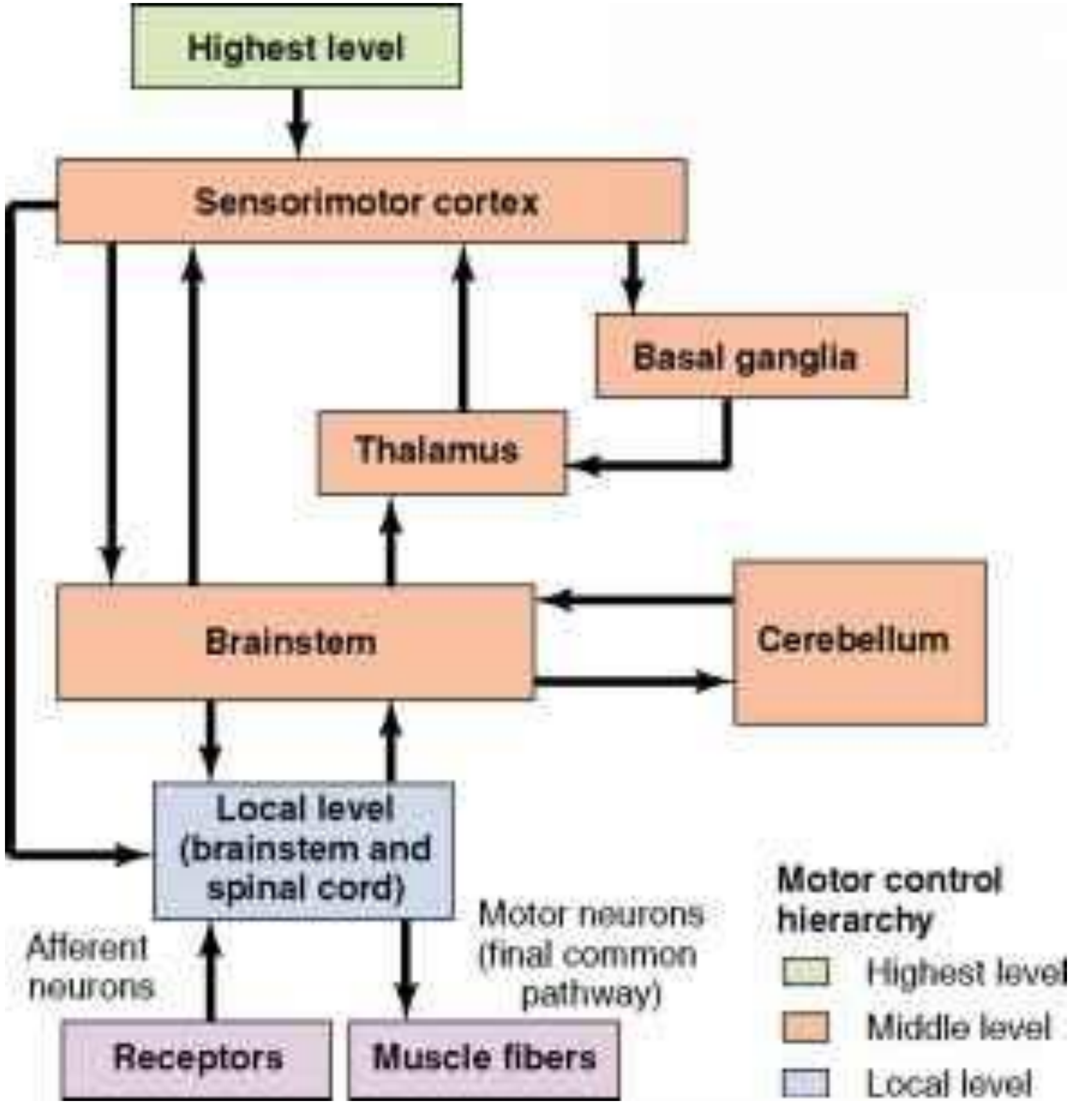
- The Bobath concept is partially based on this theory

(Shumway-Cook A 1995)

2. Hierarchical theory by Gesell and McGraw(1940)

The central nervous system (CNS) is organized in hierarchical levels.

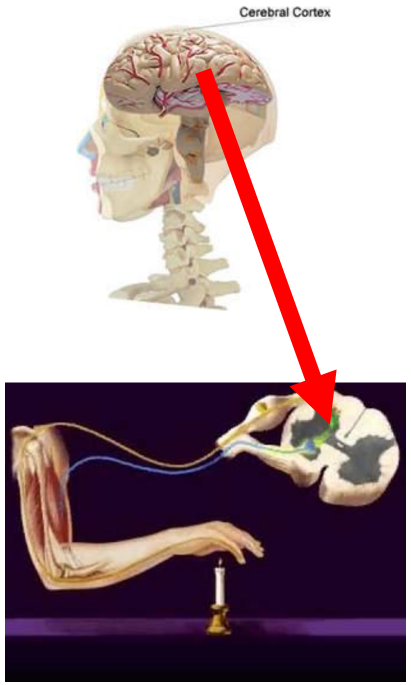
The higher association areas are followed by the motor cortex, followed by the spinal levels of motor function
(ie, the lower level is controlled by the higher level in performing movements)

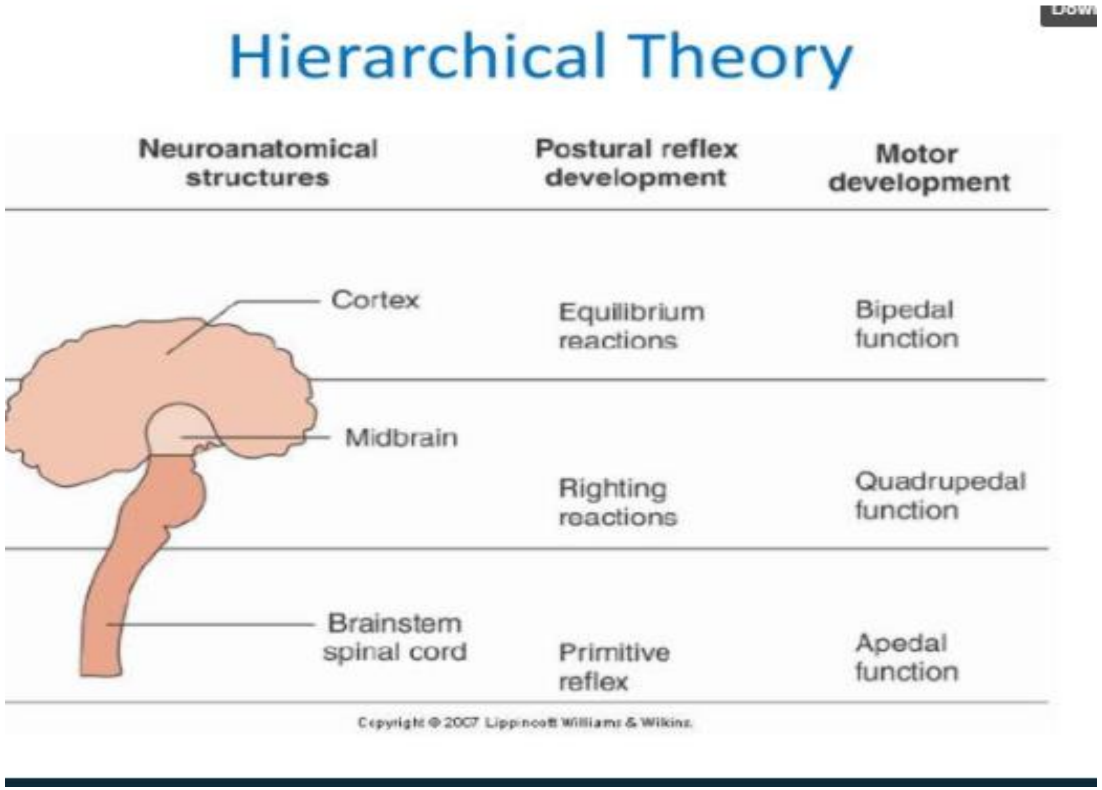


(Shumway-Cook A 1995)

2. Hierarchical theory (cont.)

The reflexes are only part of hierarchy of motor control in which higher center normally inhibit these lower reflex Centre
(eg. The primitive lower level reflexes are persisted when there is pathological changes in higher brain)





Brunnstrom stated that when higher center influence interfered, normal reflexes become exaggerated and pathological reflex appear.

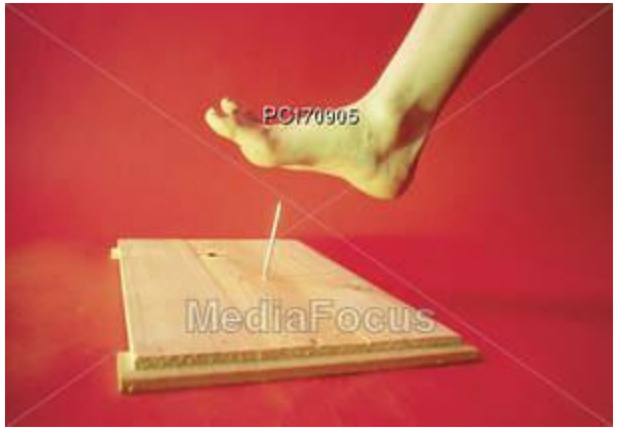
(Shumway-Cook A 1995)

2. Hierarchical theory (cont.)

Limitations of Hierarchical theory

1. The dominance of reflex behavior in certain situation

(eg. stepping on a pin results immediate withdrawal of the leg. This is lower level reflex that explains bottom up control)



(Shumway-Cook A 1995)

2. Hierarchical theory (cont.)

Clinical Implications

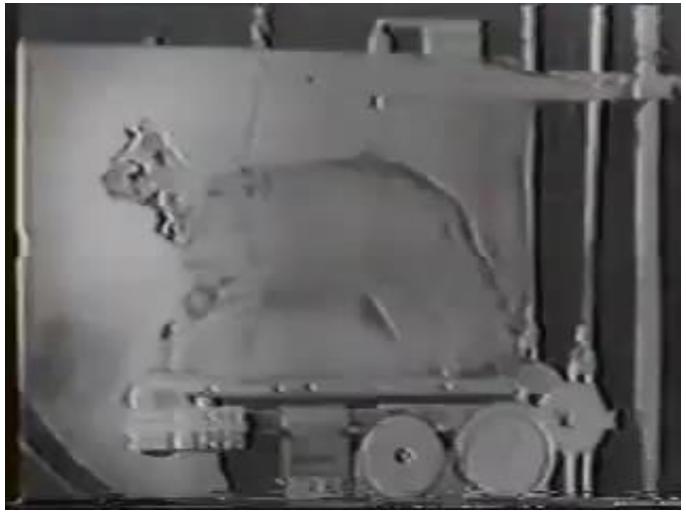
- Reflex analyses based on the hierarchical theory of MC have been performed as part of the clinical assessment for patients with neurological deficits.

- These analyses have also been used to calculate the patient’s level of neural maturity and predict functional capacity

- Brunstrom, Rood, PNF,NDT (Bobath)
- Inhibit abnormal m/m pattern to facilitate normal m/m pattern will lead to the return of functional skills.
- Repetition of normal m/m pattern will automiatically transfer to functional tasks.

(Shumway-Cook A 1995)

3. Motor programming theory



- Movement can occur in the absence of reflex action.
- The brain can hierarchically organize and store motor programs for generating movement in case of the tasks with variety of effector system.(a central motor pattern)

  Eg. In animal studies, the cat can walk on treadmill with rhythmical pattern either decerebralization or deafferentiation

- The spinal neural network would be able to produce locomotor rhythm without any sensory stimuli or descending patterns from the brain, and movement could be elicited without feedback.
- (CPGs), or specific neural circuits able to generate movements such as walking or running. Incoming sensory stimuli exert an important modulatory effect on CPGs.

(Shumway-Cook A 1995)

3. Motor programming theory (cont.)

Limitations

Does not consider that the CNS relies on musculoskeletal and environmental variables to achieve movement control

If muscles are fatigued, the movement response will be different even nervous system gives similar command

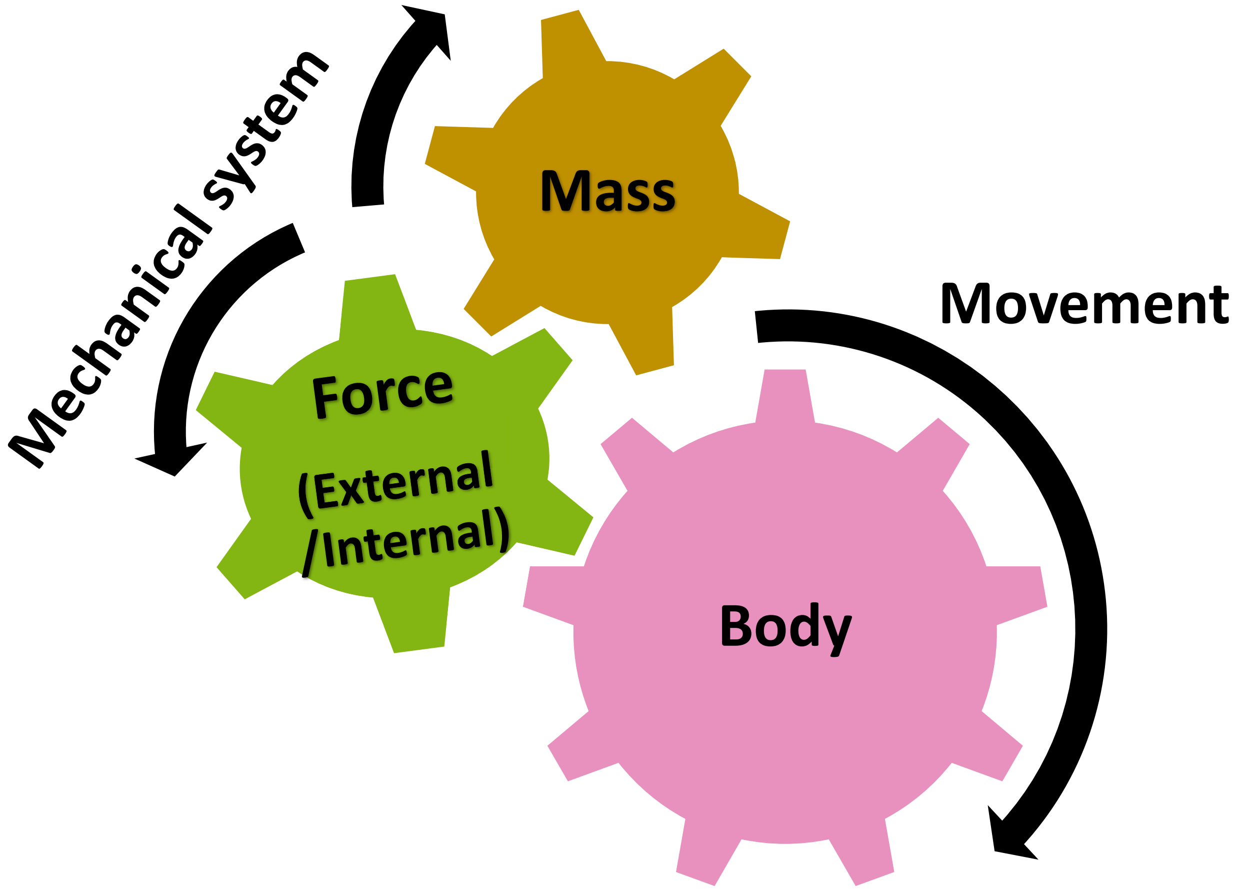
Clinical implications

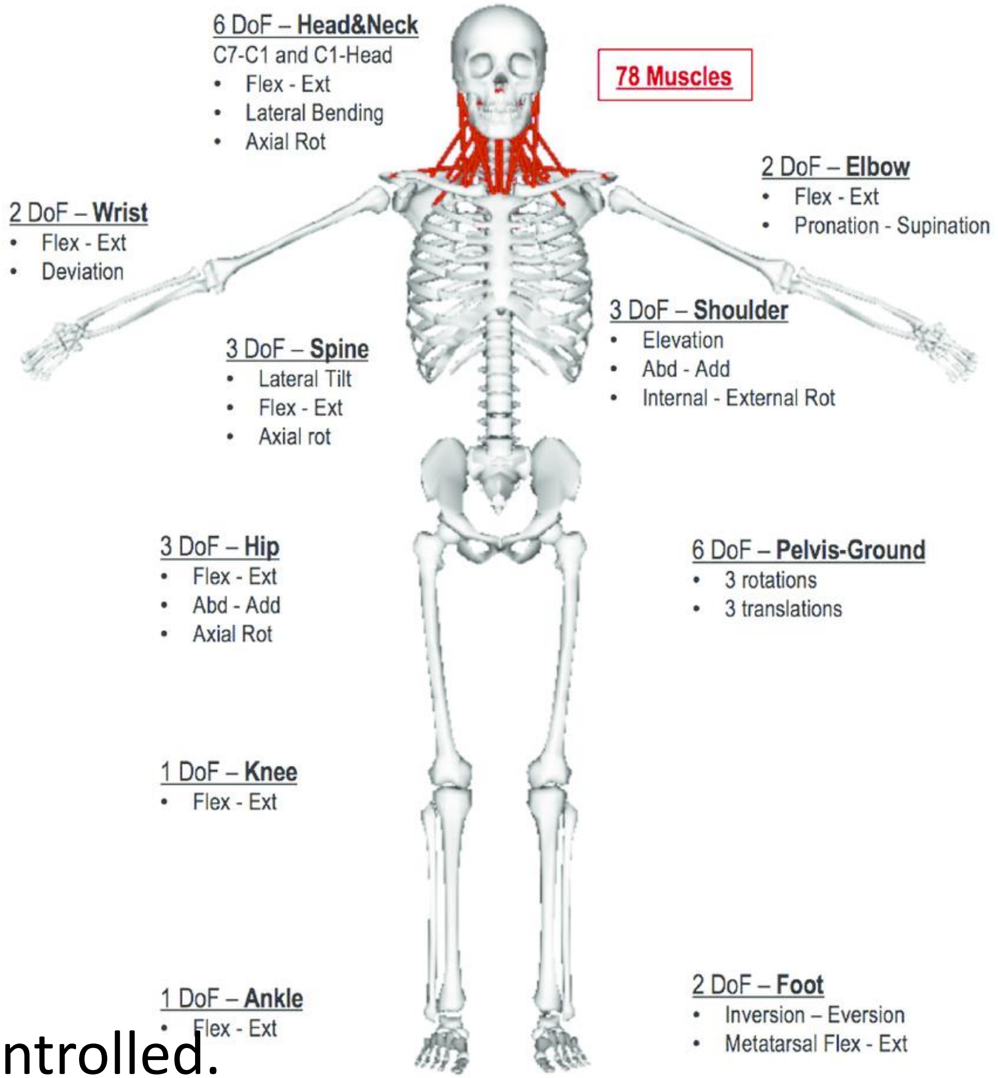
The theory emphasizes the capacity for relearning appropriate action patterns in situations of high level motor control.

Treatment should focus on recovering key movements for functional activity rather than on the retraining of isolated muscles

(Shumway-Cook A 1995)

4. Dynamic Systems theory (Bernstein, 1967)





Degrees of freedom of bone and joint need to be controlled.
Coordination of movement is the process of mastering the degrees of freedom of moving organism.

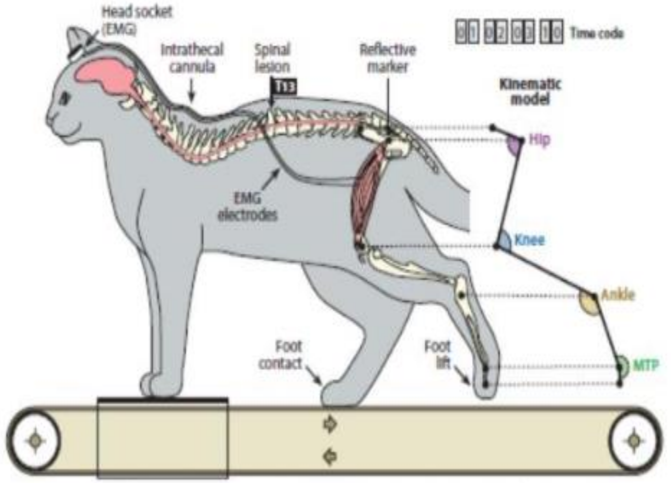
(Shumway-Cook A 1995)

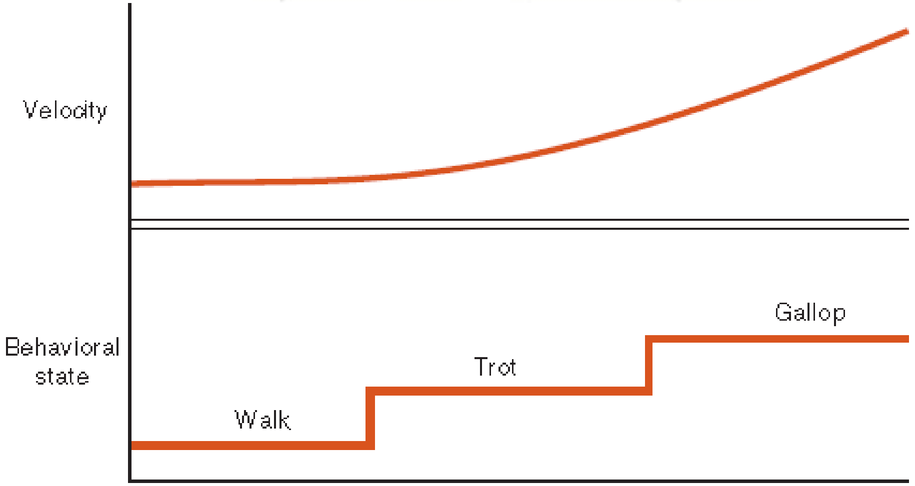
4. Dynamic Systems theory (cont.)

Movement could emerges by the interaction of elements without the need for specific commands or motor program within the nervous system.

Eg. when animal walks faster and faster, there is a poin at which, suddenly, it shifts into a trot
If animal continue to move faster, reach a second point it shift into a gallop.

A new movement emerges when a control parameter reaches a critical value





Dynamic theory explain the causes of this phenomenon, that the new movement emerges due to critical change in one of the system called a **"control parameter"**.

(Shumway-Cook A 1995)

4. Dynamic Systems theory (cont.)

Limitations

The nervous system has a fairly unimportant role

It does not focus as heavily on the interaction of the organism with the environment

Clinical implications

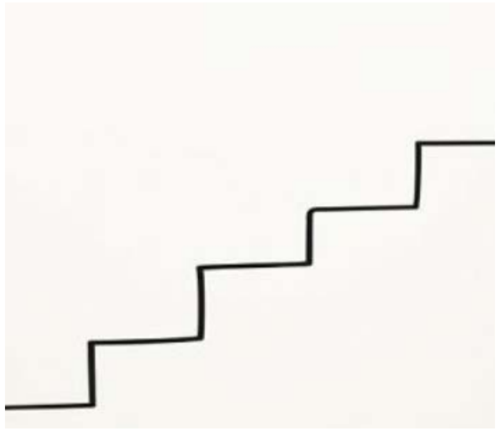
Help the retraining of a weak patient to move with greater ease with the use of momentum by interaction between speed and physical properties of the body.

For the brain lesion patient, the therapist must be careful to examine and give intervention by considering the effect of interacting impairments among multiple system including the musculoskeletal system and neural system.

(Shumway-Cook A 1995)

5. Ecological theory (by Gibson, 1960)

Motor systems



Environment

Goal-oriented behavior

It is important-

How an organism detects information in the environment?
What form this information takes?
How this information is used to modify and control movement?

(Shumway-Cook A 1995)

5. Ecological theory

Limitation

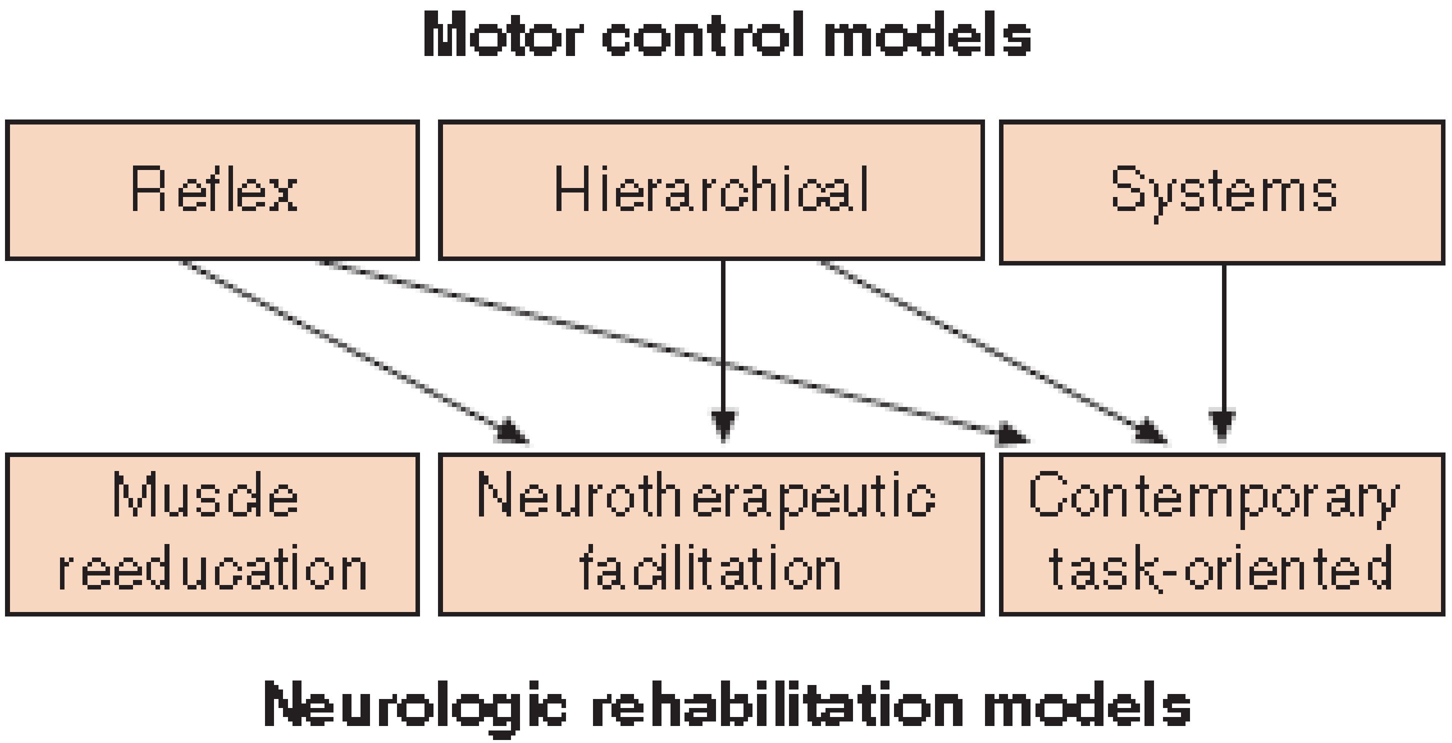
Little emphasis on the organization and function of the nervous system.

Clinical implication

It describes the subject as an active explorer of his/her environment,
Allow the subject to develop multiple ways of performing the task.

(Shumway-Cook A 1995)

Parallel Development of Clinical Practice and Scientific Theory

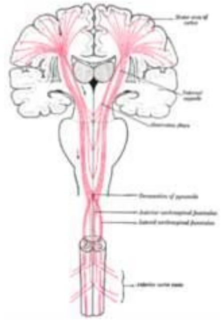


(Shumway-Cook A 1995)

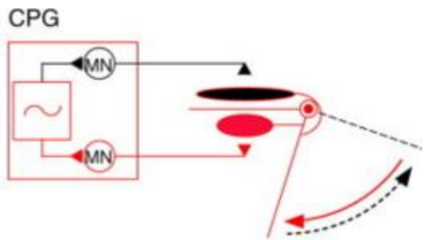
Requirements & Control mechanism

Neural control

Non-neural control



Descending influences



Marder E[1], Bucher D.2001

Pattern Generators

- Somatosensory
- Vision
- vestibular

Sensory feedback

Cognitive system

Postural control

Stepping

Adaptability

Musculoskeletal contribution

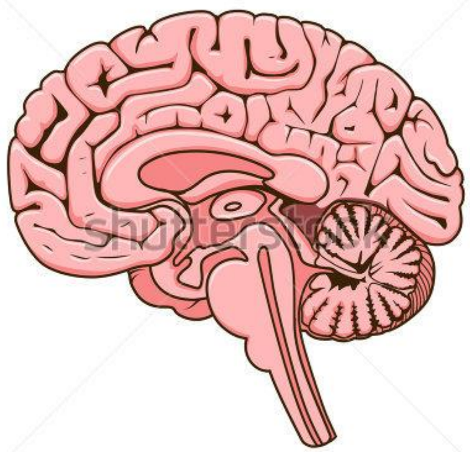
Environmental contribution

Das & McCollum, 1988, Patla, 1991

Shumway-Cook A, 2007

Systems in motor control

- **Sensory/ Perception systems**
  - Somato-sensory
  - Visual
  - Vestibular
- **Action system**
  - Motor Cortex
  - Basal Ganglia
  - Cerebellum
  - Central Pattern Generators



(Shumway-Cook A 1995)

Systems in motor control

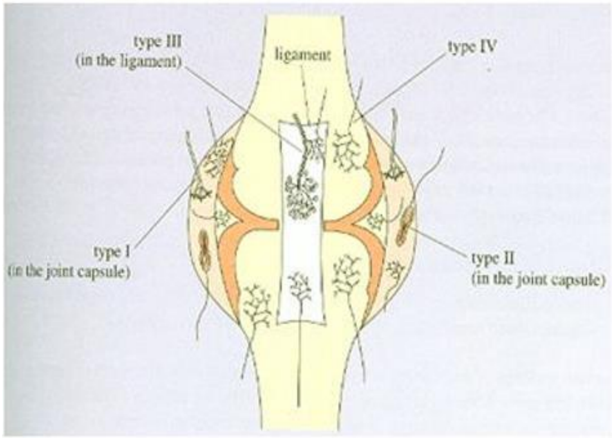
Sensory/ Perception systems

- Somato-sensory
- Visual
- Vestibular

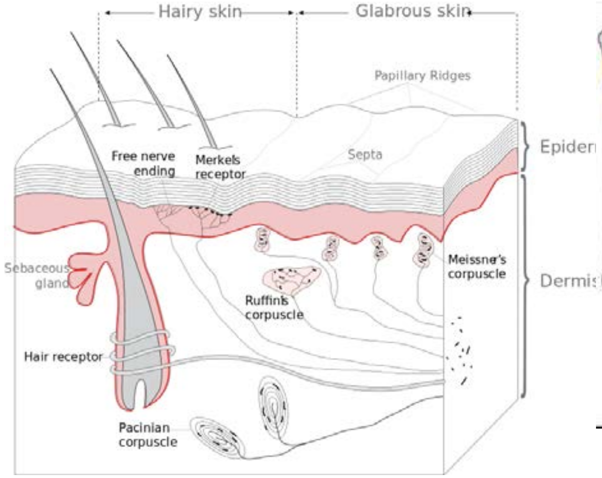
Action system

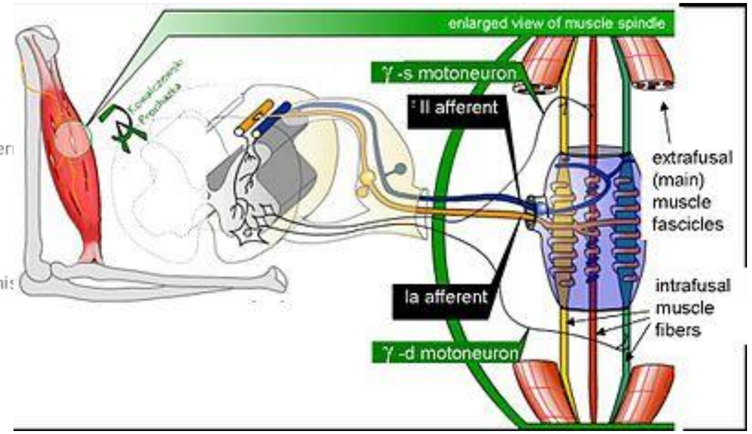
Proprioceptors

- Muscle receptors
- Joint receptors
- Cutaneous receptors
- Vestibular



Joint receptors





(Shumway-Cook A 1995)

Systems in motor control

Sensory/ Perception systems

- Somato-sensory
- Visual
- Vestibular

Action system

Provides information about the object movement in the environment

Vision and balance

- The blind show greater sway than the sighted when standing

Retina → Primary visual cortex

Dorsal stream → Posterior parietal cortex

Action vision
- Providing information specially for visual control movement

Ventral stream → Inferior temporal cortex

Perception vision
-identifying and recognizing object

(Shumway-Cook A 1995)

Systems in motor control

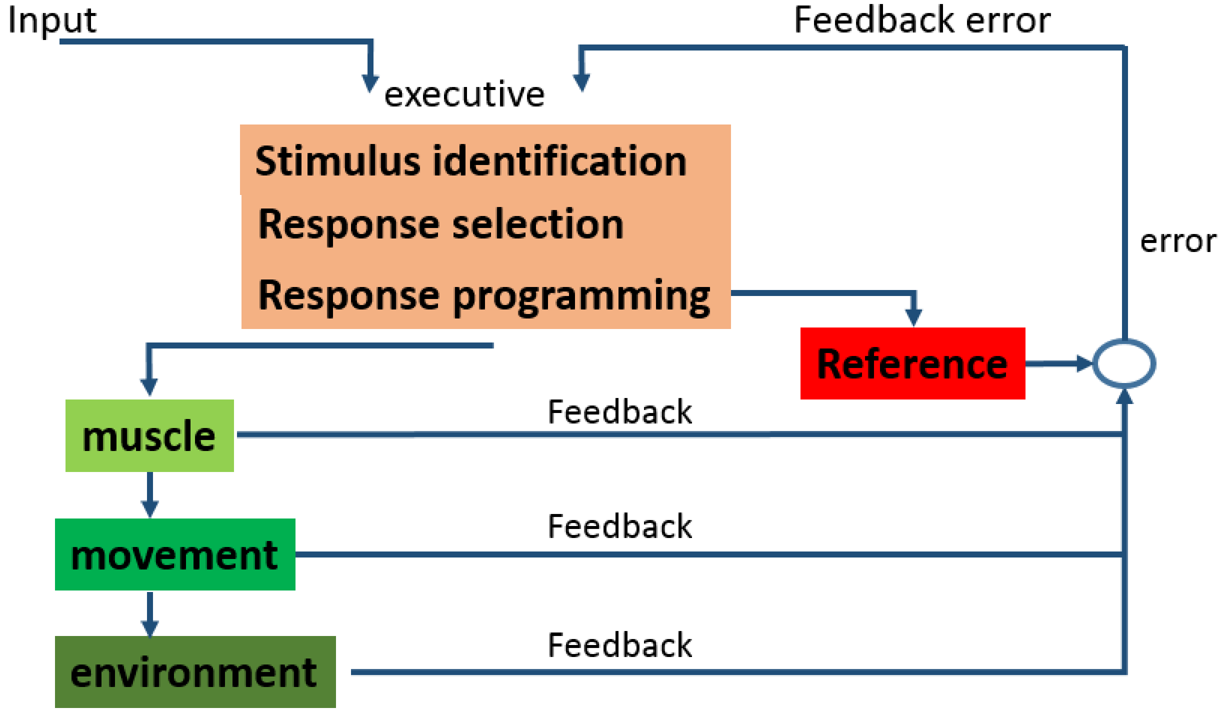
Sensory/ Perception systems

- Somato-sensory
- Visual
- Vestibular

Action system

Time to process visual feedback

- Stationary object: between 190-260 ms
- Moving object: approximately 100 ms



Visual or kinetic feed back: 150-200 ms (closed-loop)

(Shumway-Cook A 1995)

Systems in motor control

Sensory/ Perception systems

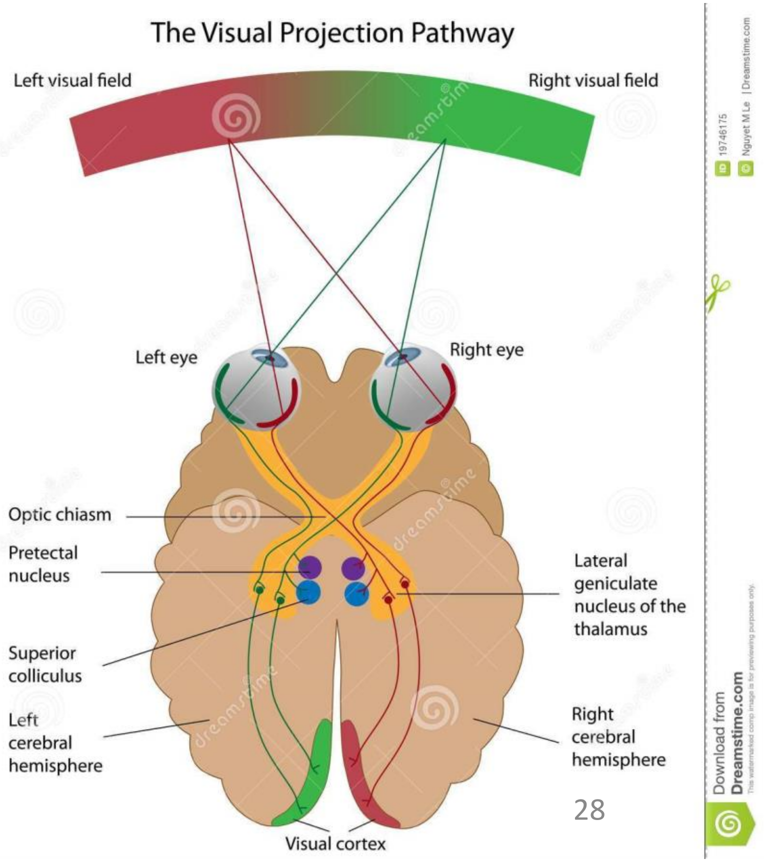
- Somato-sensory
- Visual
- Vestibular

Action system

Vision and anticipatory actions

Interceptive control

- Temporal information(when to intercept an object)
- Spatial information (where to go to intercept an object)



Systems in motor control

Sensory/ Perception systems

Action system

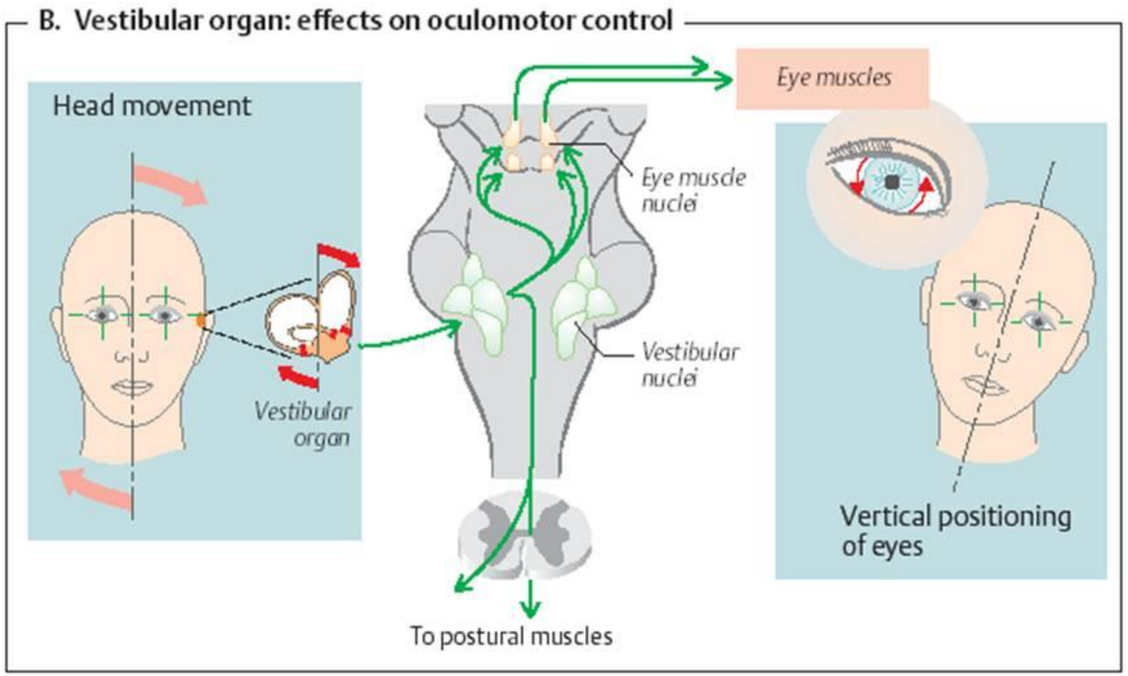
Somato-sensory | Visual | **Vestibular**

Informing about head movements respect to gravity

- Head upside down

Informing about rate and direction of spin

- Head spin
- Semicircular canals



(Shumway-Cook A 1995)

Systems in motor control

Sensory/ Perception systems

Action system

Somato-sensory

Visual

Vestibular

- Exteroceptive role

informing about nature of movements in environment

sound of the starter’s gum

- Proprioceptive role

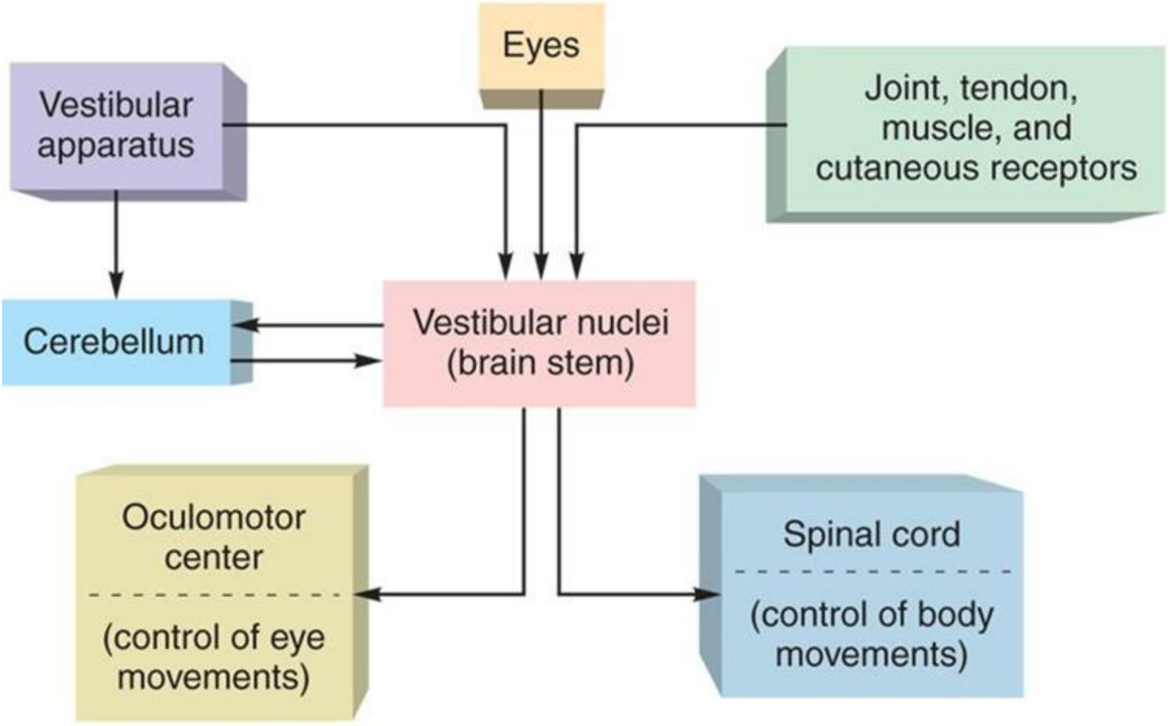
telling about our own movements

sound of footstep: walking

- Other

telling about our actions

beeps from telephone: using keypads

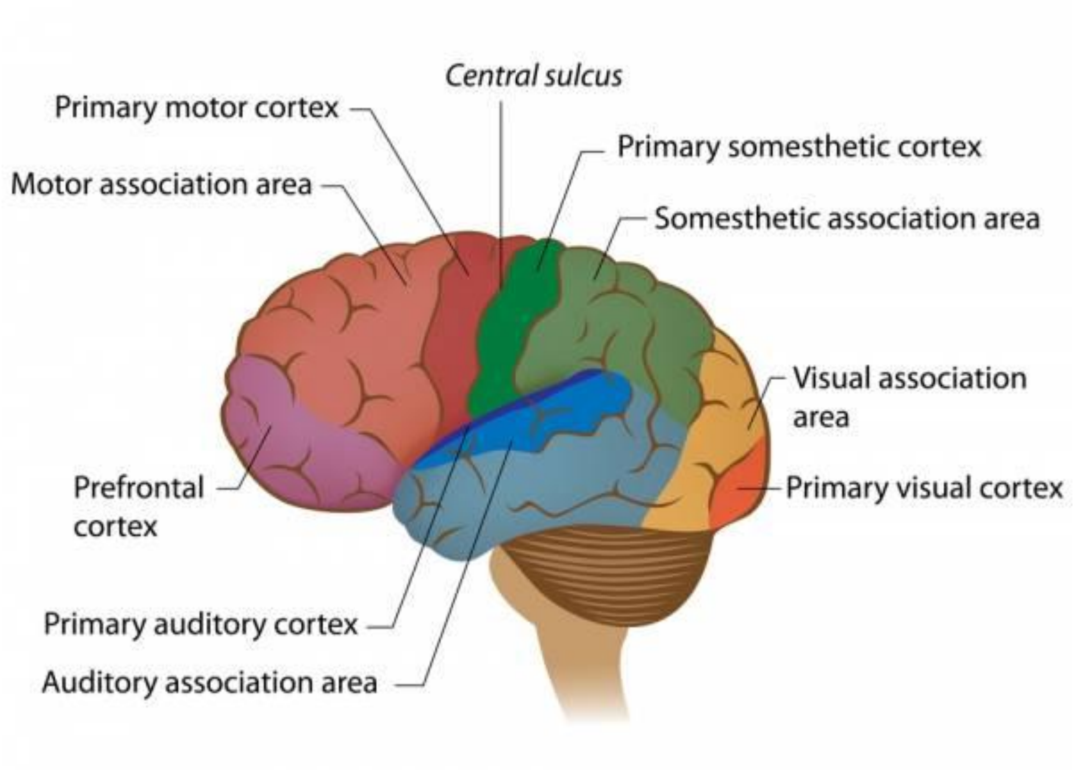


Systems in motor control

Sensory/ Perception systems

Action system

- Motor Cortex
- Basal Ganglia
- Cerebellum
- Central Pattern Generators



Central contribution to motor control

- situated in frontal lobe
- consists different processing areas such as primary motor cortex, supplementary motor area, cingulate motor area and premotor cortex

(Shumway-Cook A 1995)

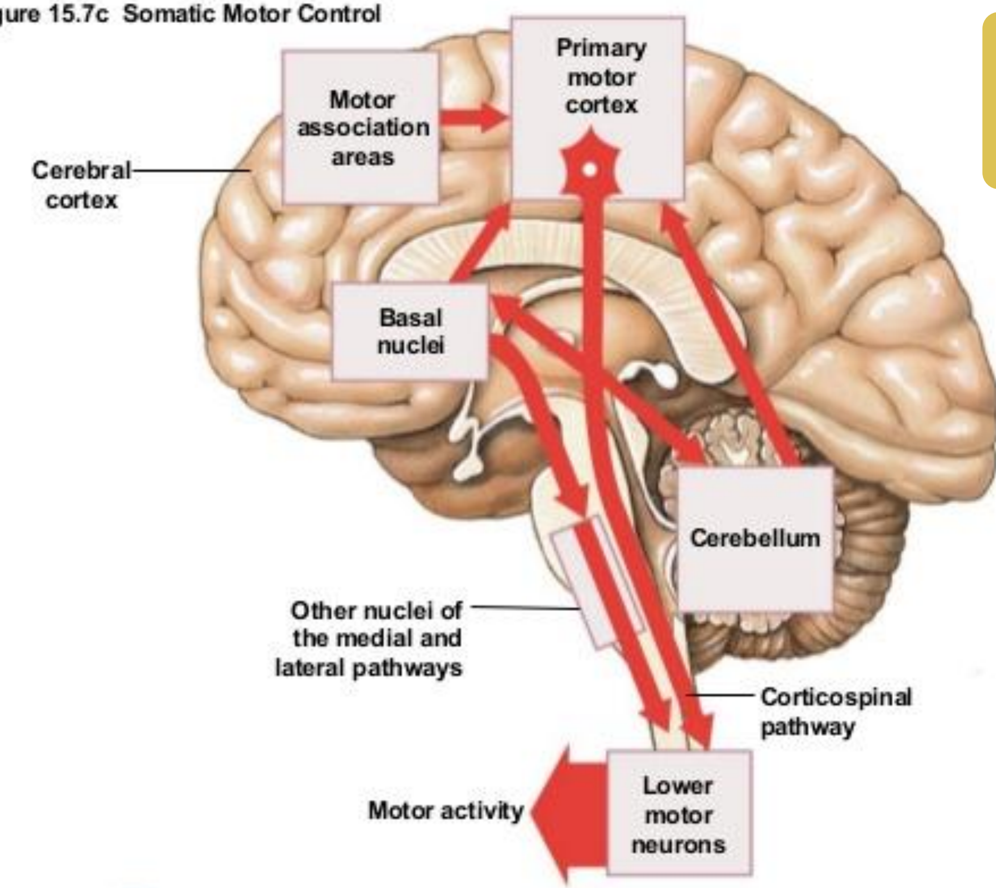
Systems in motor control

Sensory/ Perception systems

Action system

- Motor Cortex
- Basal Ganglia
- Cerebellum
- Central Pattern Generators

Figure 15.7c Somatic Motor Control



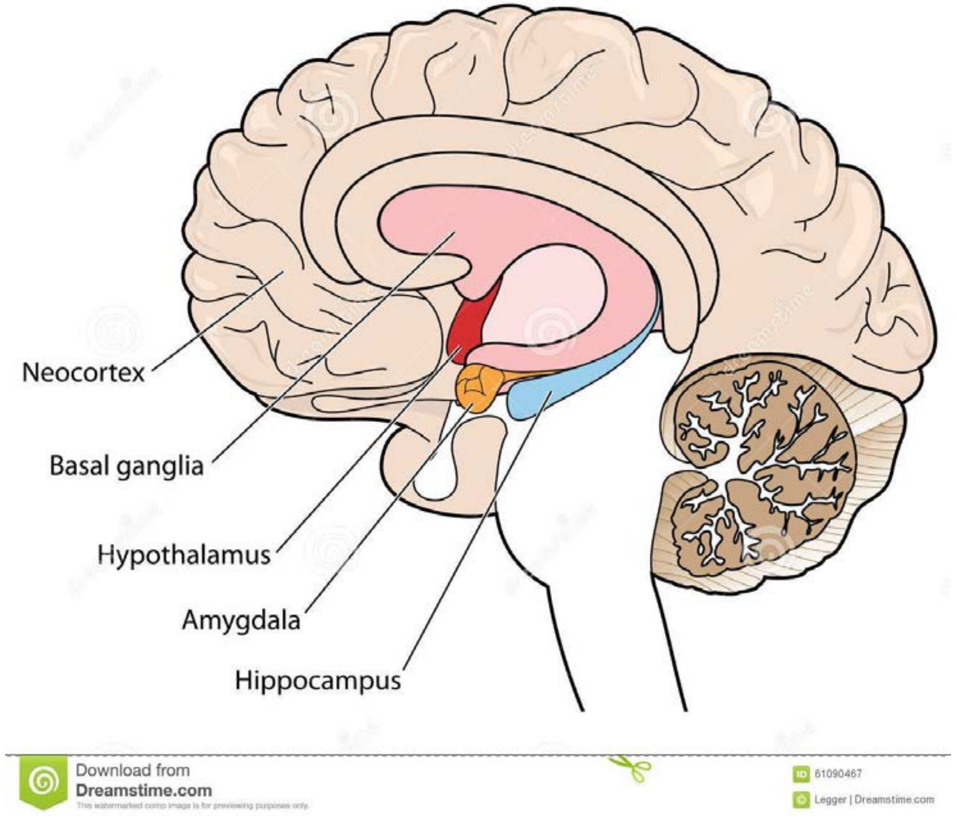
Interact with the sensory processing areas in

- parietal lobe,
- basal ganglia and
- Cerebellum

in order to identify the nature of movement, plan the movement and execute action

Systems in motor control

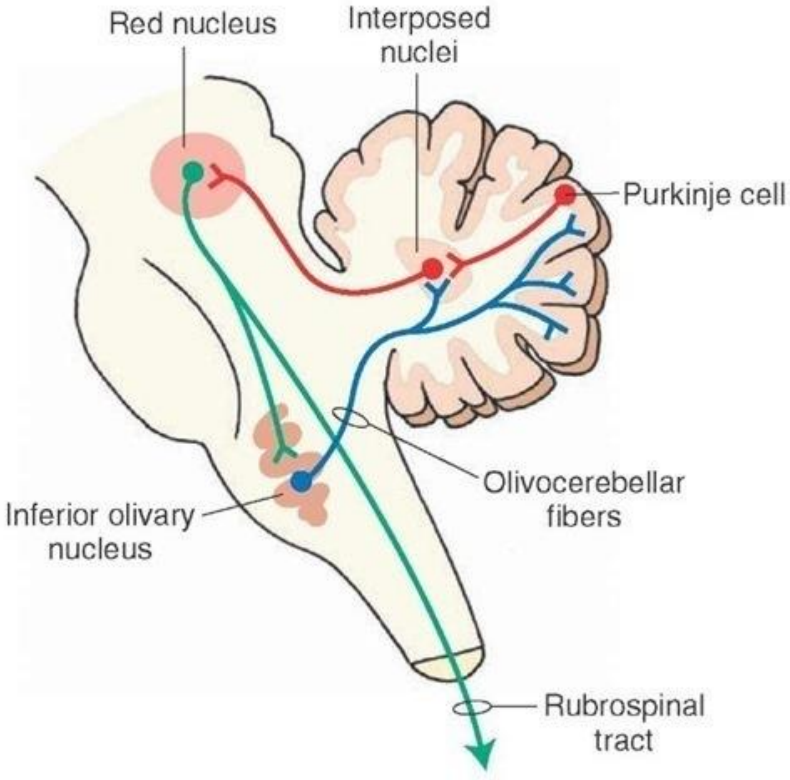
- Sensory/ Perception systems
- Action system
  - Motor Cortex
  - Basal Ganglia
  - Cerebellum
  - Central Pattern Generators



- Play vital role in coordinated movement.
- As it is part of the extrapyramidal system, lesion in this area concerned with involuntary movement and rigidity.
- It receives primary inputs from sensory, motor and association areas.
- Outputs projects to the prefrontal, supplementary and premotor cortex areas.

Systems in motor control

- Sensory/ Perception systems
- Action system
  - Motor Cortex
  - Basal Ganglia
  - **Cerebellum**
  - Central Pattern Generators



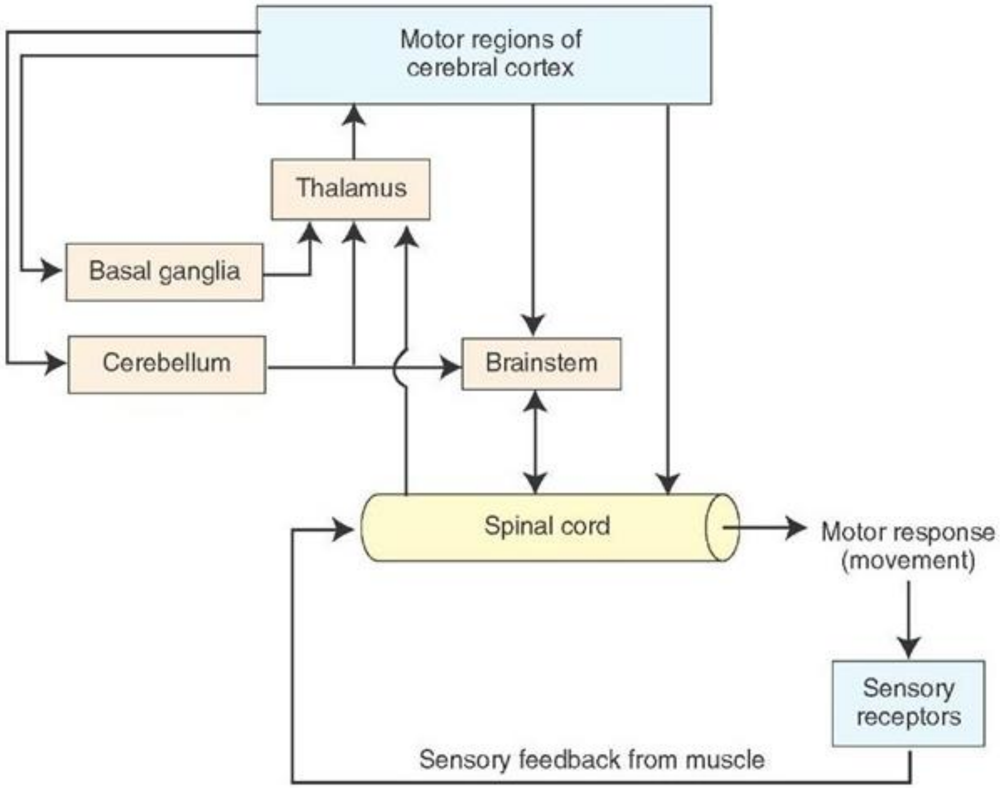
- play important role in contributing coordinated movement.
- one of the multiple feedback system that refines output of the motor system.
- receives sensory inputs about programming and execution of movements from corticopontine, somatosensory inputs form spinal cord, visual, auditory and vestibular inputs.

Systems in motor control

Sensory/ Perception systems

Action system

- Motor Cortex
- Basal Ganglia
- **Cerebellum**
- Central Pattern Generators



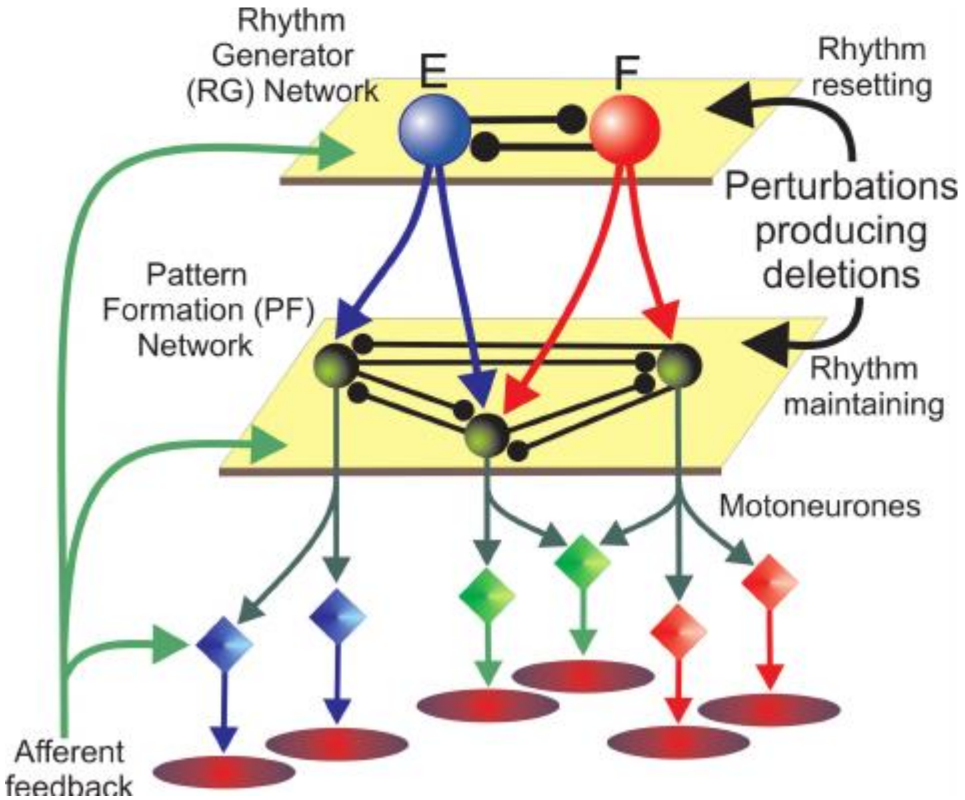
- It receives sensory inputs about programming and execution of movements from corticopontine, somatosensory inputs form spinal cord, visual, auditory and vestibular inputs.

Systems in motor control

Sensory/ Perception systems

Action system

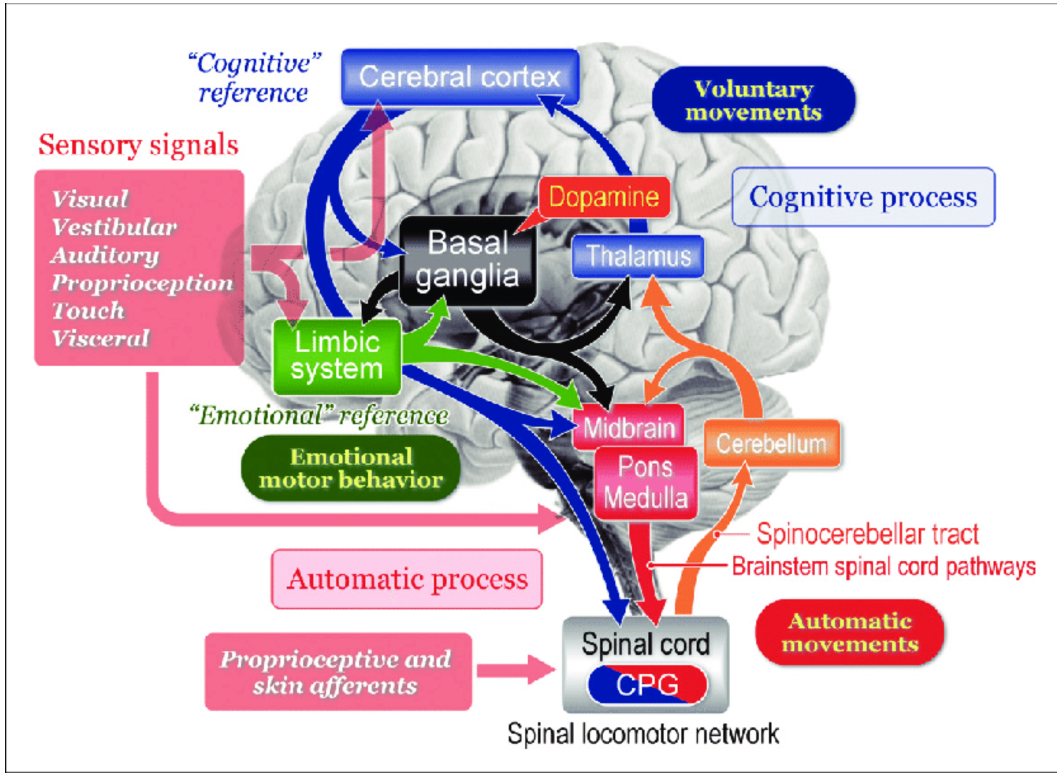
- Motor Cortex
- Basal Ganglia
- Cerebellum
- **Central Pattern Generators**



- The basic rhythmical locomotor movement pattern is generated in flexor and extensor half centers of spinal locomotor networks (central pattern generator- CPG).
- The rhythm interneuronal activity is sent to the second order interneurons then transmitted to the target motorneurons innervating ipsilateral limb muscles through their excitatory and inhibitory actions.

Systems in motor control

Sensory/ Perception systems



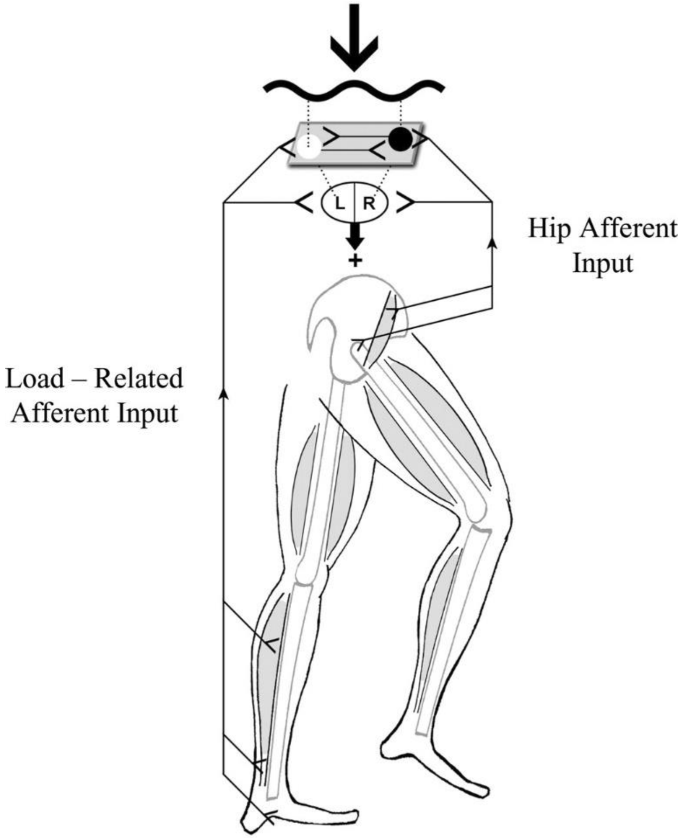
Action system

- Motor Cortex
- Basal Ganglia
- Cerebellum
- Central Pattern Generators

The midbrain, subthalamic and cerebellum locomotor regions also take an important role in activation and modulation to the rhythm and pattern of locomotion generated in CPG .

Systems in motor control

- **Sensory/ Perception systems**
- **Action system**
  - Motor Cortex
  - Basal Ganglia
  - Cerebellum
  - Central Pattern Generators



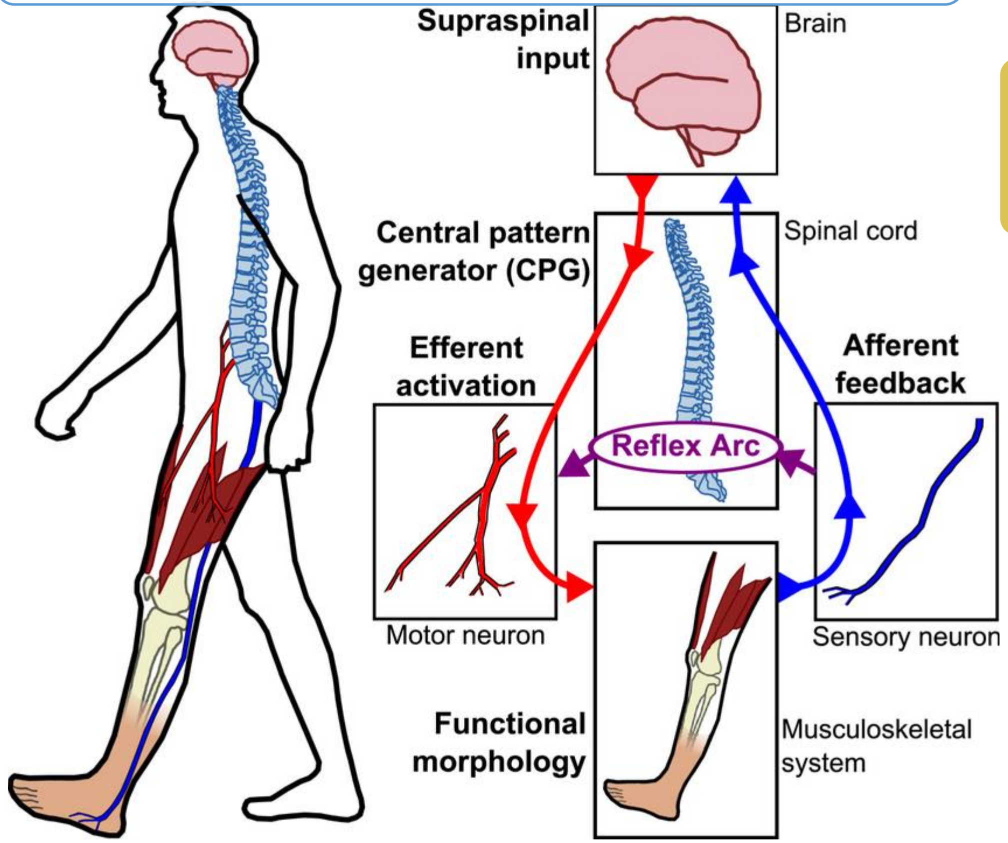
- The interneurons in the spinal cord also projects to the contralateral side contribute to the left right alteration of the limb movement.
- This reciprocal activities are able to generate in the absence of sensory inputs but are modulated by these sensory afferents.

Systems in motor control

Sensory/ Perception systems

Action system

- Motor Cortex
- Basal Ganglia
- Cerebellum
- Central Pattern Generators



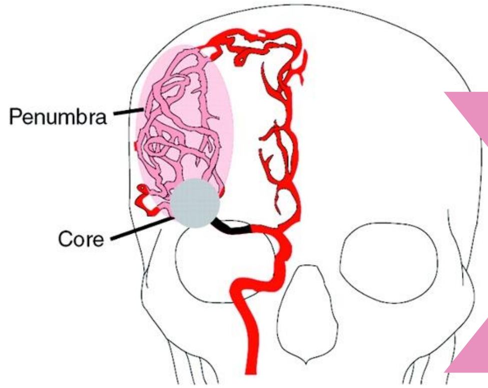
- The inhibitory system in brainstem have an influencing effect on the inhibitory interneurons in the spinal cord.
- This inhibitory interneurones are considered to be excited for inhibition upon alpha and gamma motorneurones innervating extensor and flexor muscles thus correspondingly take part in controlling rhythm and pattern of locomotion.

MOTOR LEARNING CONCEPTS

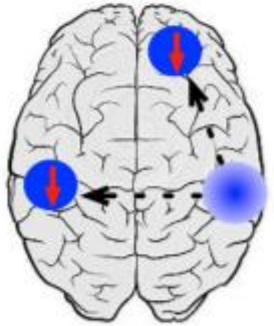
Motor learning is a set of processes associated with practice or experience leading to relatively permanent changes in the capability for skilled movement

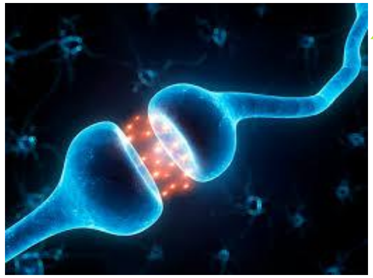
(Krakauer 2006)

Stages of Functional Recovery



Diaschisis in functionally connected cortical areas





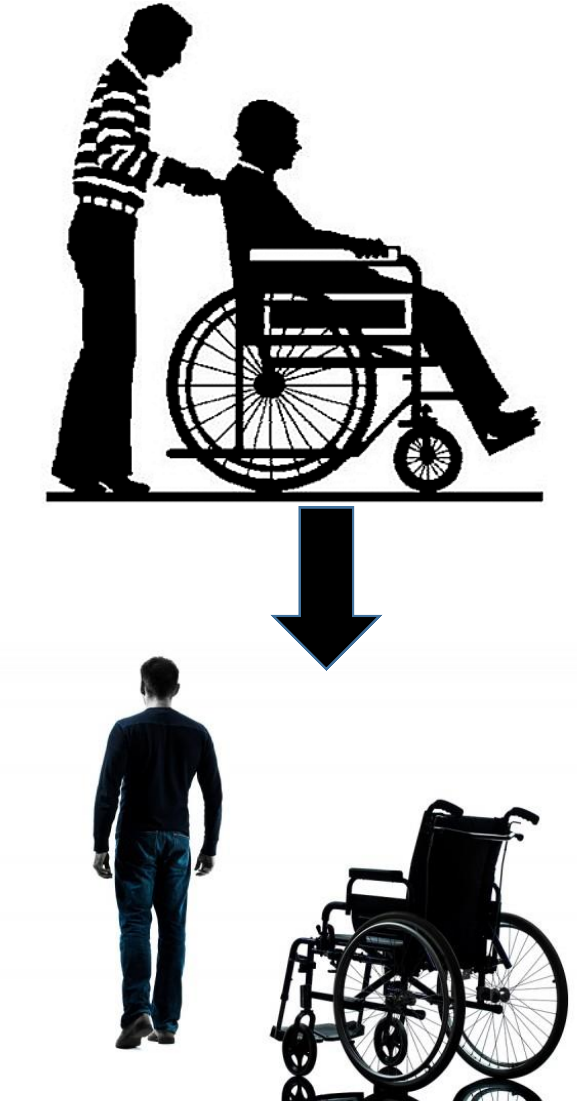
Early recovery

1. Resolution of post stroke edema
2. Reperfusion of ischemic penumbra
3. Resorption of local toxins
4. Recovery of partially damaged ischemic neurons

Late recovery (Neural plasticity)

(Ability of nervous system to modify structural & functional organization)

1. Collateral sprouting of new synaptic connections
2. Unmasking of previous latent functional pathways
3. Reversibility from diaschisis



(Kelly, et al. 2003)

Principle of Neural plasticity

Skill Meaningful activities in enriched environment

Short term changes ↔ changes in synaptic efficiency

Repetitions

Neural modifiability

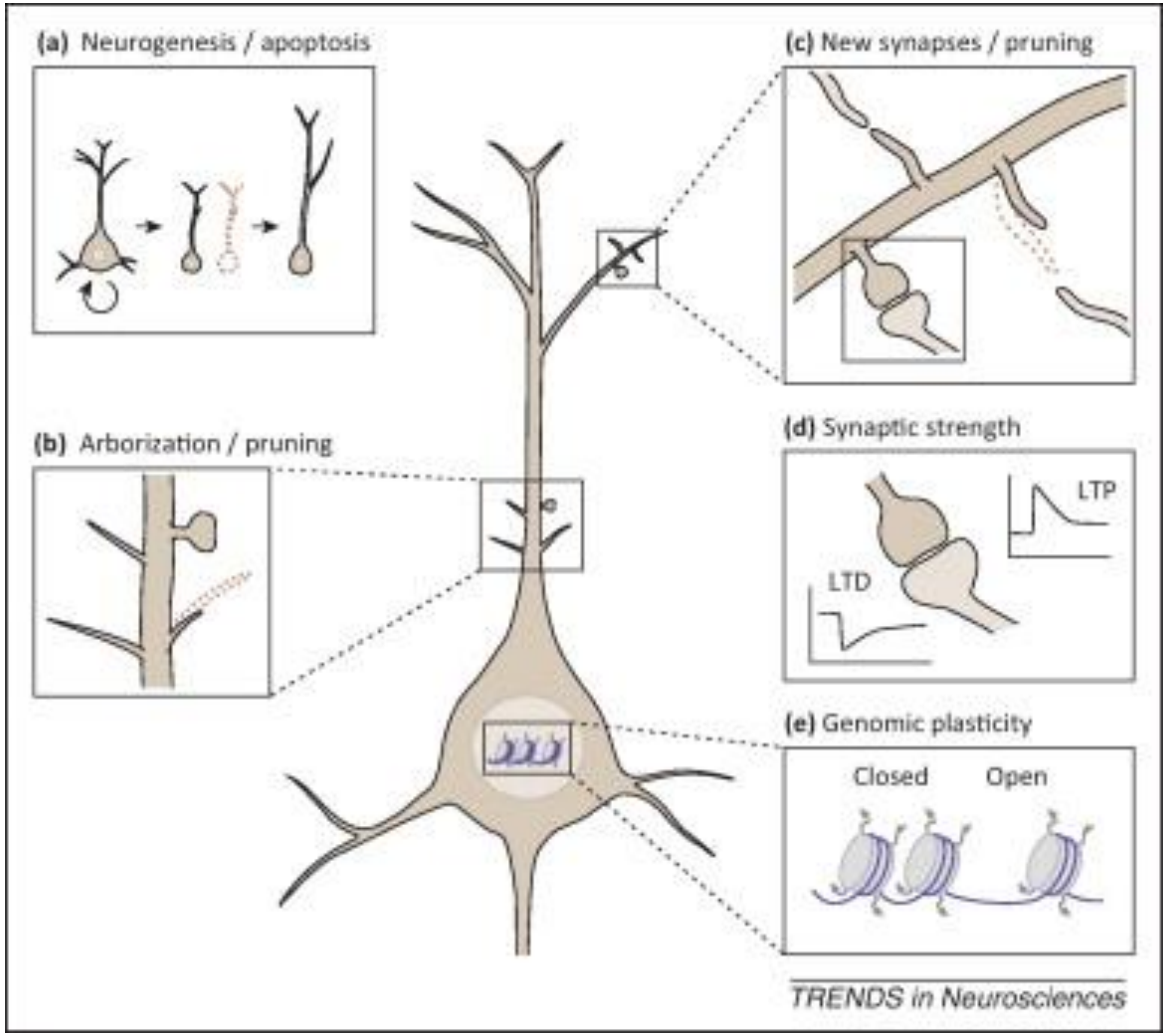
Long term changes ↔ structural changes in synaptic connections

Functional recovery

Neural plasticity

(Shumway Cook-A, 2007) (Kleim JA & Jones TA, 2008)

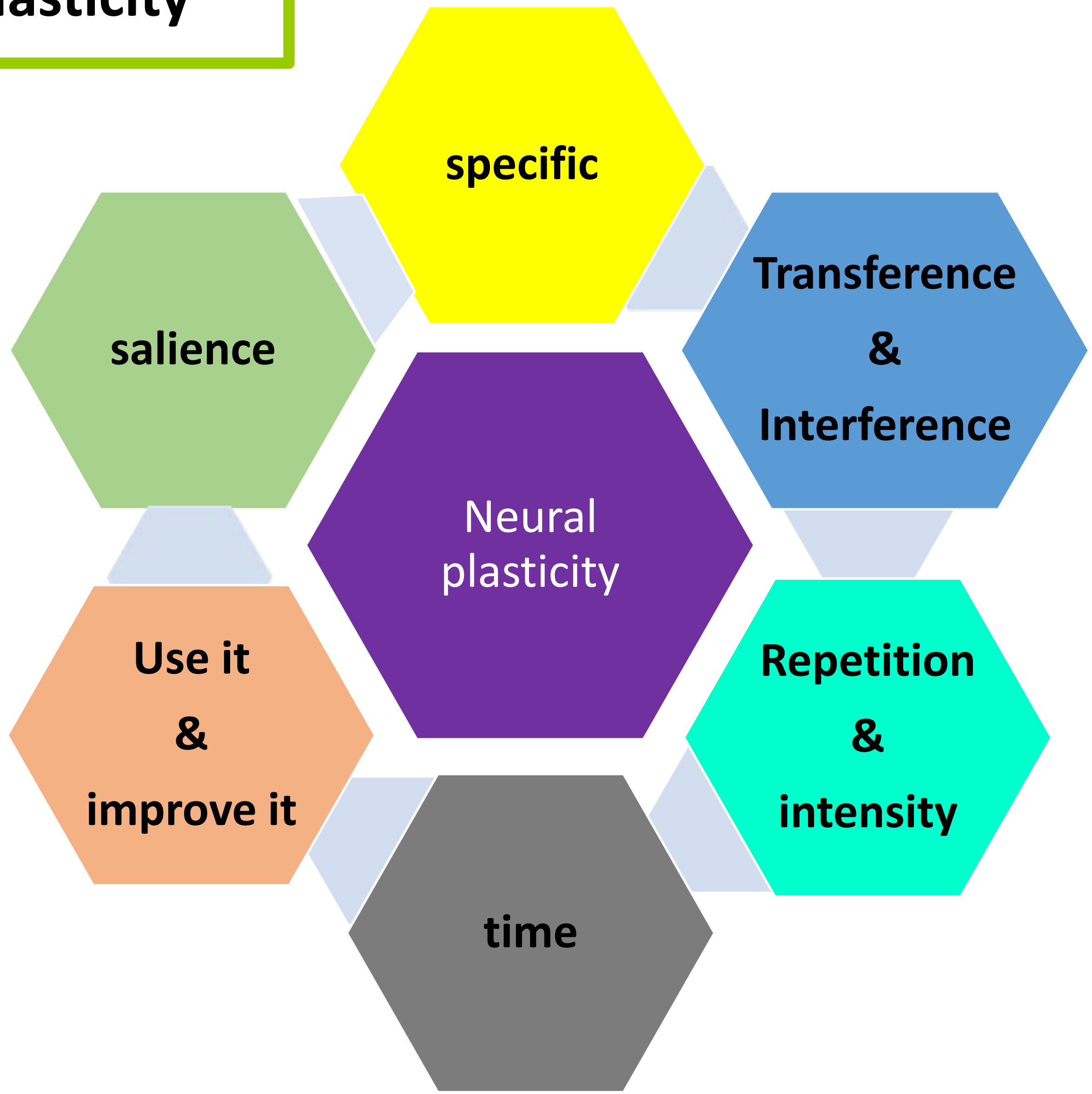
Principle of Neural plasticity



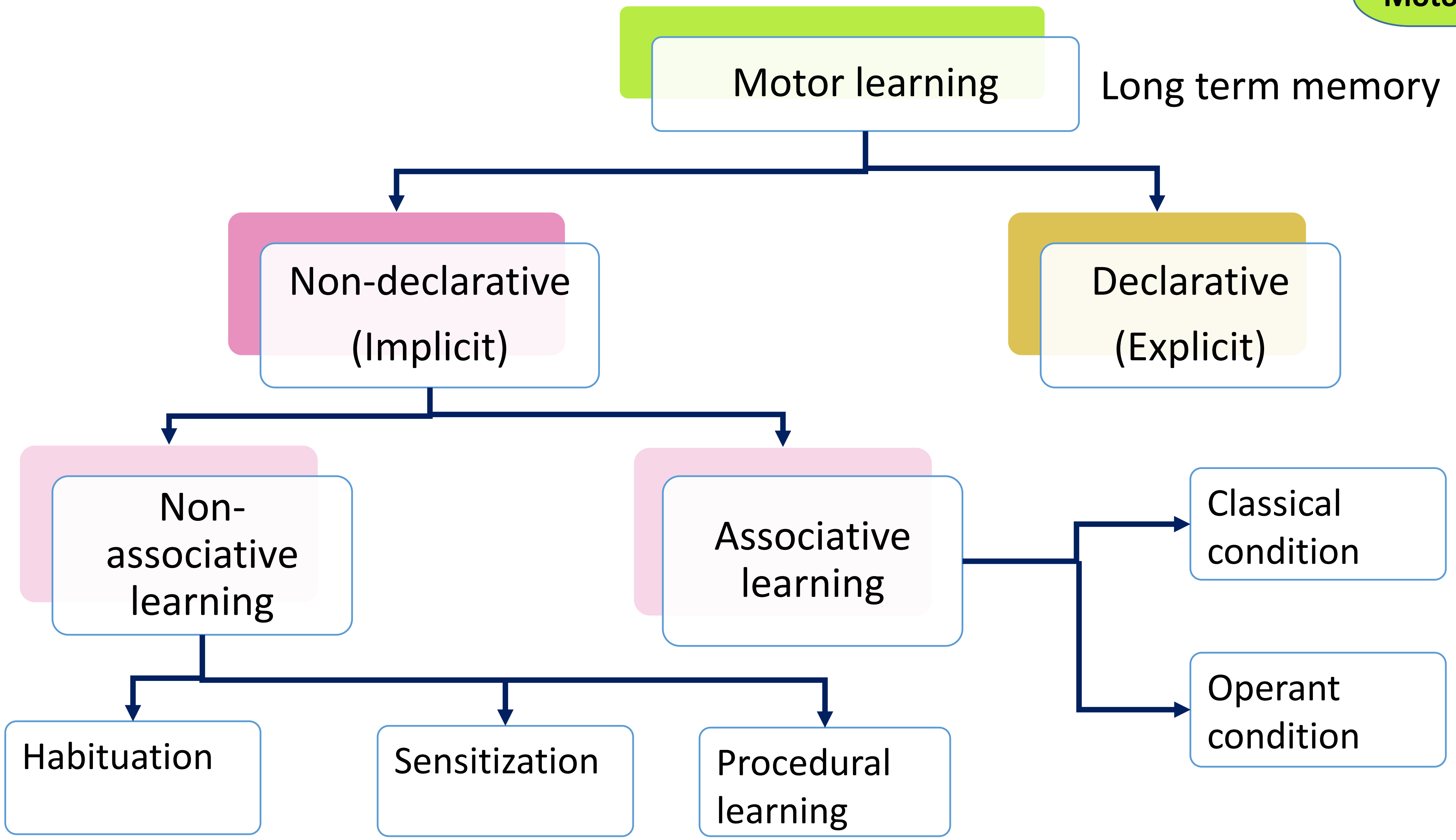
- Decrease or increase excitatory postsynaptic potential
- Changes in synaptic efficiency
- Synthesis of new protein
- Formation of new synaptic connections
- Cortical mapping

(Kleim JA & Jones TA, 2008)

Principle of Neural plasticity



(Kleim JA & Jones TA, 2008)



(Carr and Shepherd, 1987)

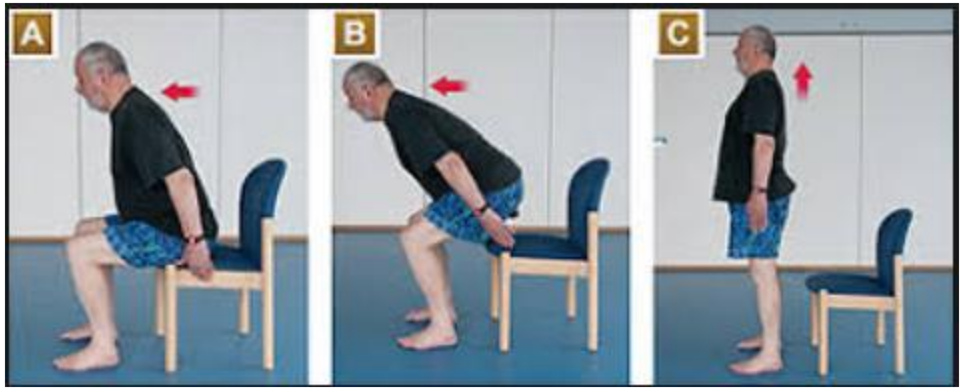
Motor learning

Non-declarative (Implicit)

Declarative (Explicit)

Knowledge that can be consciously recalled and thus requires processes such as awareness, attention, and reflection
(medial temporal lobe, sensory association cortex, Hippocampus)

Constant repetition can transform declarative into non-declarative or procedural knowledge.



Motor learning

Non-declarative (Implicit)

Declarative (Explicit)

Non-associative learning

When animals are given a single stimulus repeatedly, the nervous system learns about the characteristics of that stimulus.

Habituation

Ability to discontinue response to highly repetitive stimuli
-Decrease in strength of behavior
Eg. Habituate jumping reflex to loud sound

(Reflex pathway)

Motor learning

Non-declarative (Implicit)

Declarative (Explicit)

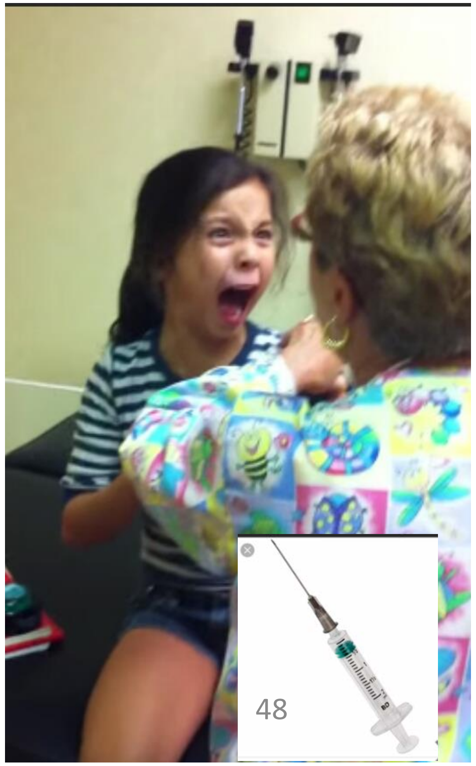
Non-associative learning

Sensitization

(Reflex pathway)

Increase in responsiveness as a result of
- Repeated application of stimulus
- Aversive stimulus

Increase in strength of behavior



Motor learning

Non-declarative (Implicit)

Declarative (Explicit)

Non-associative learning

Procedural learning

(Striatum & other motor area)

Learning tasks that can be performed automatically without attention or conscious thought, like a habit

Procedural learning develops slowly through repetition of an act over many trials

Motor learning

Non-declarative (Implicit)

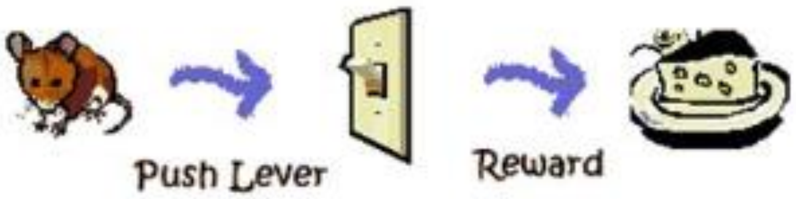
Declarative (Explicit)

A person learns to predict relationships

Associative learning

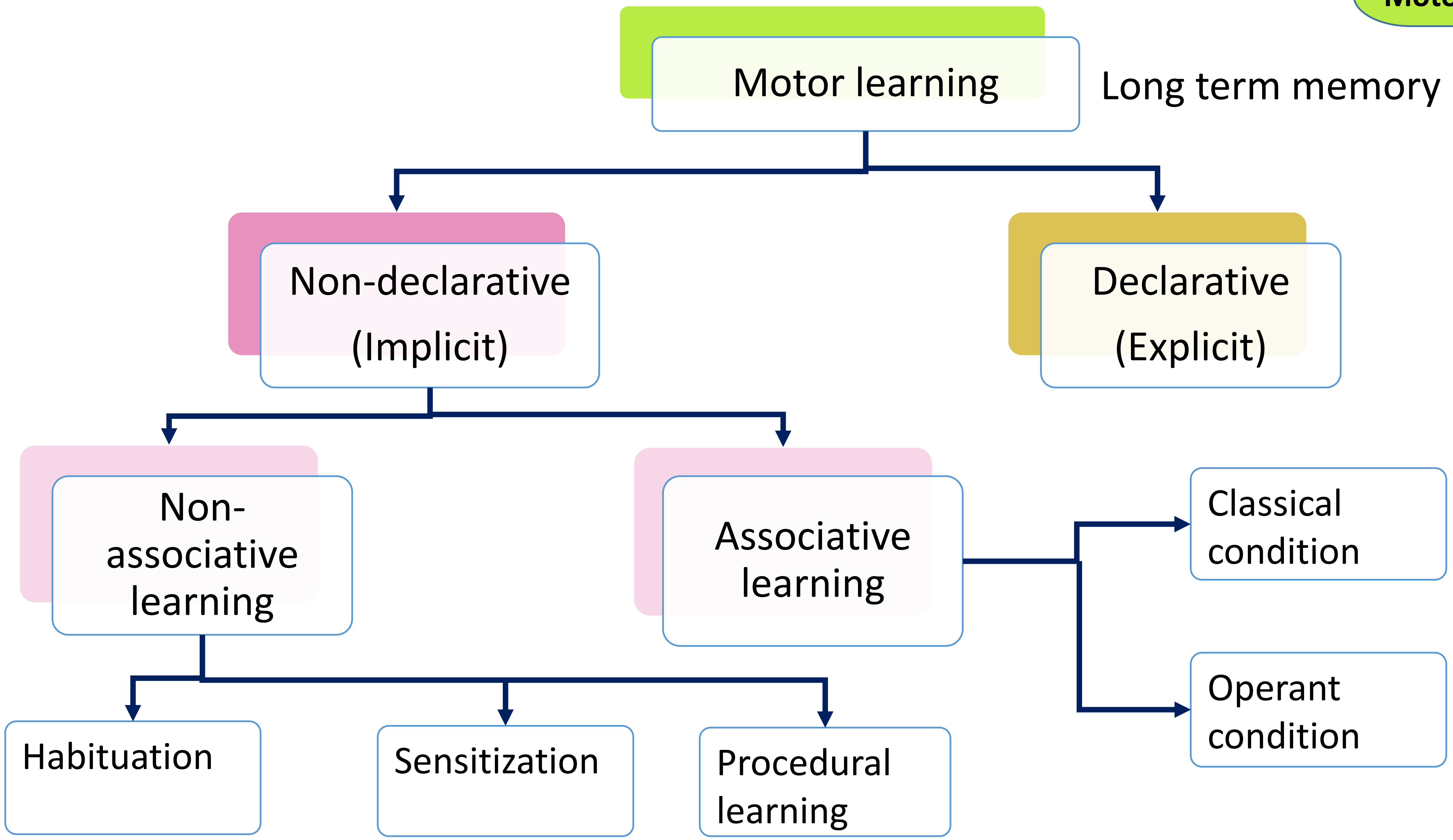
Classical condition (Amygdala, cerebellum, premotor cortex)

The relationships of one stimulus to another



Operant condition

The relationship of one's behavior to a consequence


Motor learning
Long term memory
Non-declarative
(Implicit)
Declarative
(Explicit)
Non-associative learning
Associative learning
Classical condition
Operant condition
Habituation
Sensitization
Procedural learning

Motor learning theories

1. Adams's Closed- Loop Theory
2. Schmidt's Schema Theory
3. Ecological Theory

Theories on motor learning stages

1. The Fitts and Posner 3-stage model
2. Bernstein's 3-stage model
3. Gentile's 2-stage model

1. Adams's Closed- Loop Theory (Jack Adams)

Based upon the concept of closed-loop process in motor control, Sensory feedback is used for the ongoing skilled movement.

Two distinct types of memory such as

Memory trace (initiates movement) → *Perceptual trace* (movement was carried over and detected error)

The more practices of the specific movement by the individual, the stronger the perceptual trace and the less incorrect movements would become.

- For example, practices picking up a glass more and more, the perceptual trace for movement is developed and thus guides later movements to be more accurate.

(Adams 1971)

1. Adams's Closed- Loop Theory (Jack Adams)

Limitation of Adam's theory

Could not explain in learning certain movements such as

- animal able to walk treadmill even there is no sensory afferent
- the acquisition of novel movement, (violinist can play cello even without practicing how to play cello)

It is impossible to store a separate perceptual trace for every performed movements because of memory storage process in the brain.

Recent research evidence shows that practicing a movement in various ways enhances more improvement in motor performance of the task than practicing a single movement end point alone

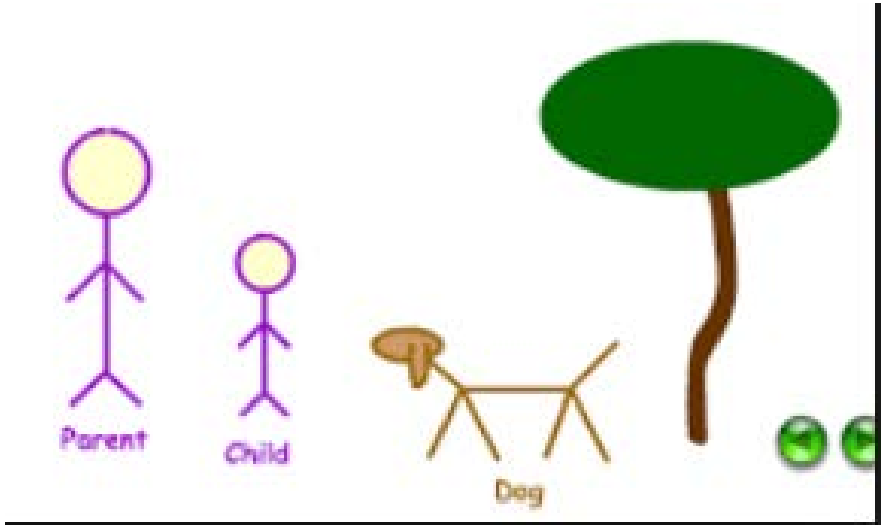
(Shea & Shebilske, 1993).

2. Schmidt's Schema Theory (Richard Schmidt)

Generalized the motor program theory in motor control with the use of schema concept

The term **schema** originally referred to an abstract representation stored in memory following multiple presentations of a class of objects

He proposed that motor programs are stored in the memory by generalizing the rules such as spatial and temporal patterns of muscle activities needed to carry out a given movement



(Schmidt & Lee, 2005).

2. Schmidt's Schema Theory (cont.)

When individual makes movement, short term memory stores four things

1. initial movement conditions such as position of body and weight of object manipulated,
2. the parameter used such as force,
3. outcome of movement
4. sensory consequences of movement such as feeling, looking and sound.

(Schmidt & Lee, 2005).

2. Schmidt's Schema Theory (cont.)

Then these 4 things are abstracted into two schemas:

1. **The recall schema** is created in nervous system by the relationship between the size of parameter and the movement outcome.

2. **The recognition schema** is used to evaluate the response by gathering the sensory consequences and outcomes of previous similar movements together with the current initial conditions to create the future sensory consequences.

(Schmidt & Lee, 2005).

2. Schmidt's Schema Theory (cont.)

Limitation of Schema theory

Lack of specificity.

Unable to explain

- how the generalized motor programs created, i.e, how a person makes first movement before any schema exists.
- immediate acquisition of new type of coordination.

For example, a centipede will immediately produce a quadripedal gait pattern after two pairs of limbs are removed

(Kugler et al. 1980).

3. Ecological Theory (Karl Newell ,1991)

Based upon the system theory and ecological theory of motor control.

- Motor learning is occurred by the coordination of perception and action under the task and environmental constraints.
- This optimal strategy consists not only finding the appropriate motor response for the task but also the most appropriate perceptual cues for the optimal task solution.
- The perceptual information is a feedback occurred during and after the movement and is related to the understanding of task goal and the movements to be learned.

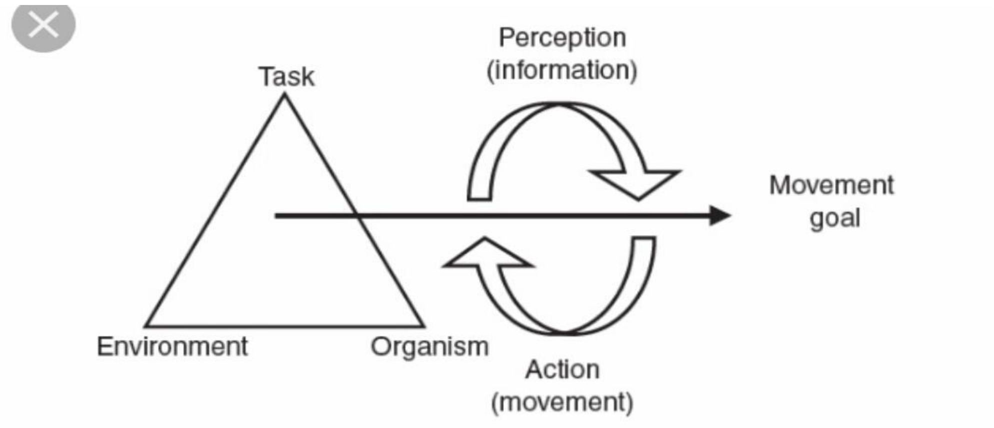
3. Ecological Theory(Cont.)

Clinical implication

This theory can be applied in clinical practice,

Example: practicing reaching and lifting different glass that contain variety of substances facilitates learning with relevant perceptual cues for reaching and lifting different size, slippery surface and fullness of the glass.

If an individual is unable to recognize this perceptual cues, the motor strategy will be less than optimal, ie, the fluid may spill out or the glass may slip.



Theories on motor learning stages

1. The Fitts and Posner 3-stage model
2. Bernstein’s 3-stage model
3. Gentile’s 2-stage model

1. The Fitts and Posner 3-stage model

Cognitive stage

- learns a new skill,or relearns an existing one.
- need to practice the task frequently, with outside supervision and guidance;
- important to make mistakes and know how to correct them in this process.

Associative stage

- perform the task in a situation with specific environmental restrictions
- make fewer errors during the activity and complete it more easily
- begin to understand how the different components of a skill are interrelated

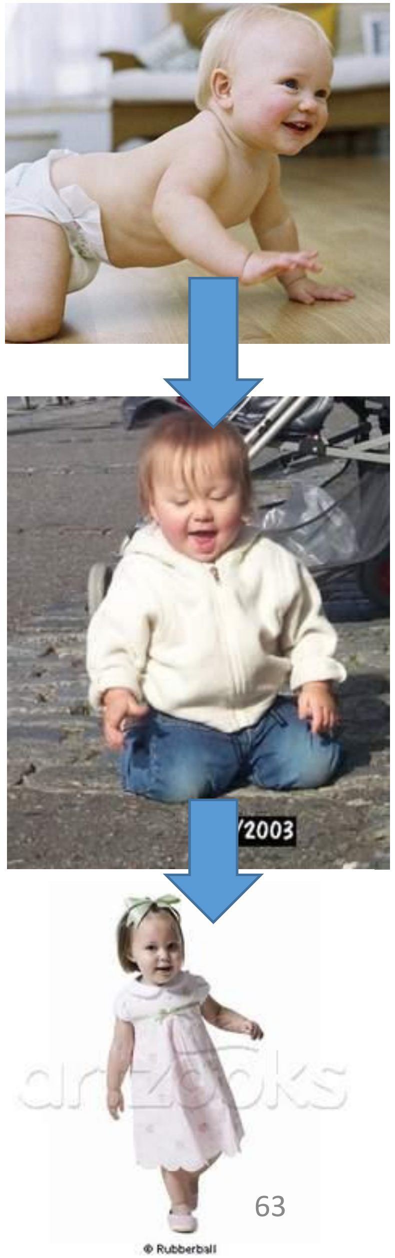
Autonomous phase

- move in a variety of settings and maintain control throughout the task.
- retain a skill and apply it in different settings through automatisation

2. Bernstein's 3-stage model

Bernstein's model emphasizes quantifying degrees of freedom

- Initial stage, the individual will simplify his or her movements by reducing the degrees of freedom.
- Advanced stage, the individual will gain a few degrees of freedom, which will permit movement in more of the articulations involved in the task.
- Expert stage possesses all the degrees of freedom necessary in order to carry out the task in an effective and coordinated manner



3. Gentile's 2-stage model

The first stage

- Understanding the purpose of the task
- developing movement strategies appropriate for completing the task
- interpreting environmental information that is relevant to organizing movement.

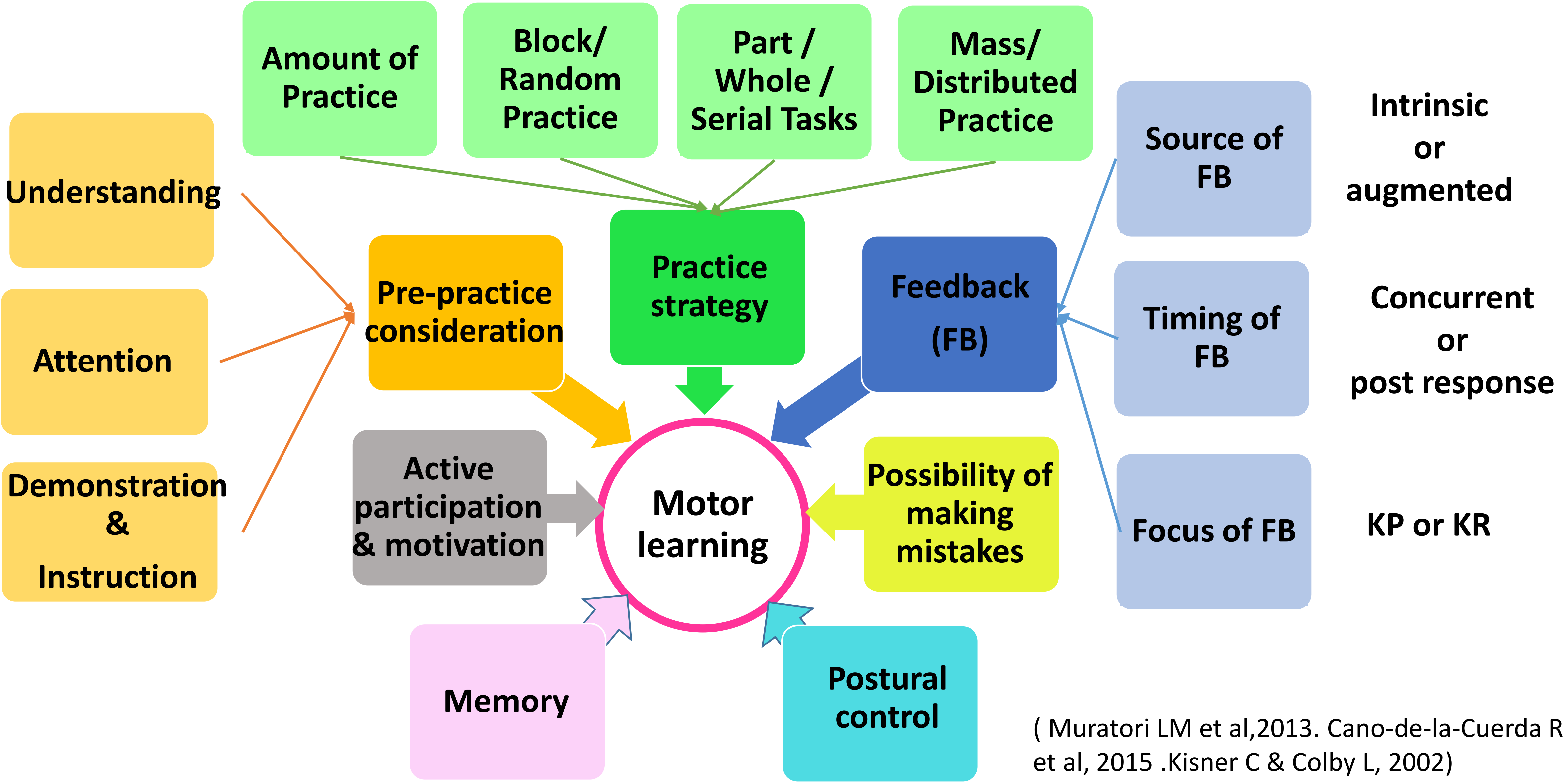
The second stage

(fixation or diversification)

The subject aims to redefine movement, which includes both developing the capacity

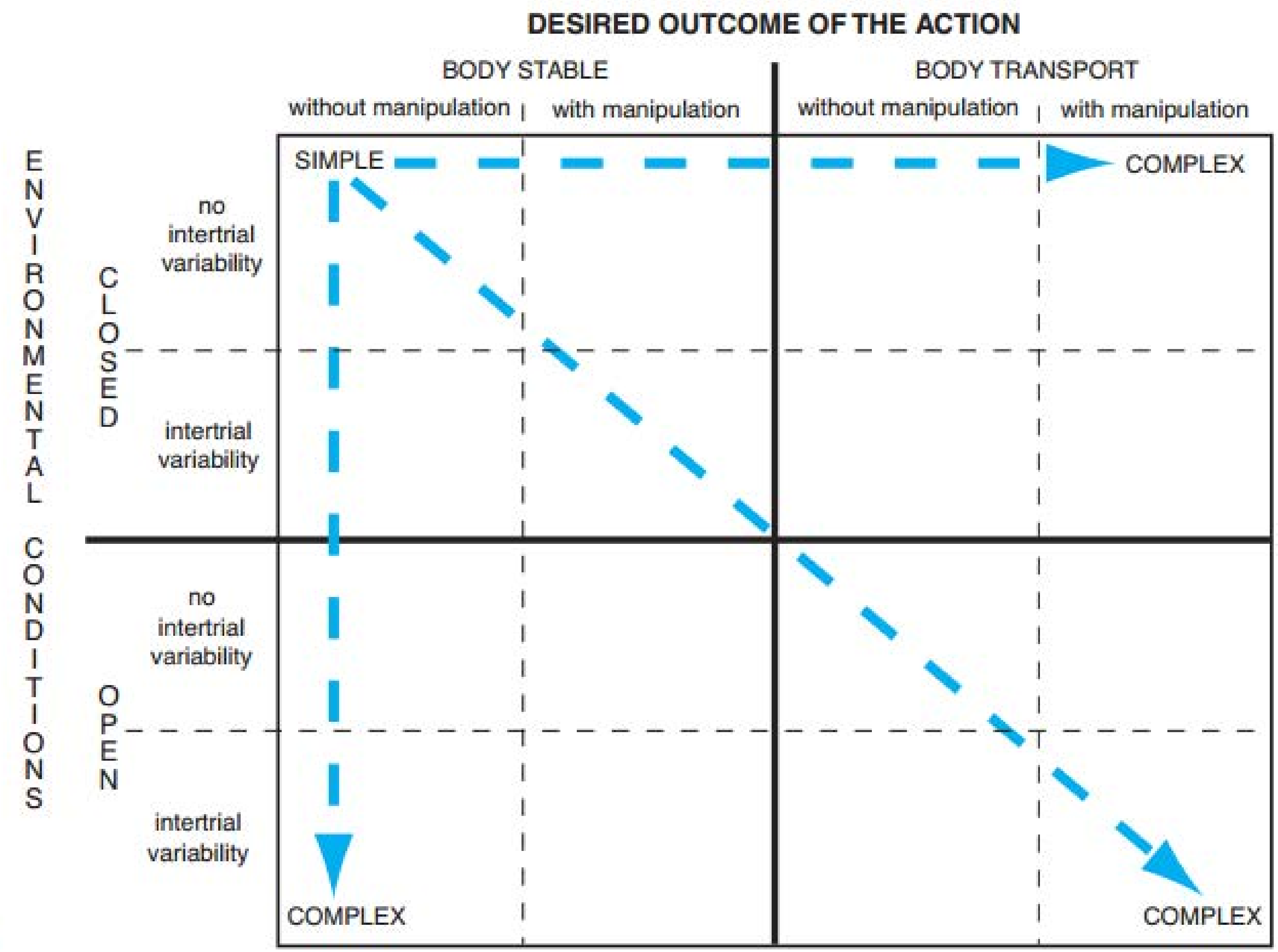
- to adapt movement
- to change in task and in setting
- being able to perform the task consistently and efficiently

Motor learning principles and influencing factors



(Muratori LM et al,2013. Cano-de-la-Cuerda R et al, 2015 .Kisner C & Colby L, 2002)

Taxonomy of motor tasks



Dennis, JK, McKeough, DM, 1993

Taxonomy of motor tasks

		BODY STABLE		BODY TRANSPORT	
		without manipulation	with manipulation	without manipulation	with manipulation
CLOSED	without intertrial variability	Maintaining balance in sitting on bed while caregiver combs hair Maintaining balance in standing in hallway as caregiver buttons coat	Sitting at the table and eating a meal Sitting doing household accounts Sitting at desk to write a letter	Rolling over in bed Sit <=> stand from bed Tub transfers Bed <=> bathroom, using same route daily	Carrying a tray of food or drinks from the kitchen to the living room, using the same tray and same route each time
CLOSED	with intertrial variability	Maintaining sitting balance on different chairs in the room e.g., rocker, straight-backed chair, sofa. Maintaining standing balance on different surfaces: carpet, wood	Standing in the kitchen unloading a dish-washer Sitting on a low stool in the yard, bending over to weed the vegetable garden	Rolling over in a twin bed and a queen bed Sit <=> stand from different heights and surfaces Up and down curbs of different heights	Carrying a tray of food or drinks from the kitchen to the living room, using different trays and routes each time
OPEN	without intertrial variability	Maintaining balance in a moving elevator	Rearranging packages while standing in a moving elevator	Walking up or down a moving escalator or a moving sidewalk	Rearranging packages while walking up or down the moving escalator
OPEN	with intertrial variability	Maintaining sitting or standing balance in a moving bus	Drinking a cocktail on the deck of a cruise ship	Community ambulation Walking through a living room where children are playing	Shopping in the supermarket Walking a precocious pet on a leash

Dennis, JK, McKeough, DM, 1999


Thank You