Motor control models and neurophysiotherapy

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There are many models of motor control and many theories of motor learning

On them different therapeutical models and approaches are based

Models of motor control

- Reflex
- Hierarchical
- Engineering
- Systems
- Neurophysiological/information processing
- Biomechanical
- Neuroplasticity (?)
- Ecological
- Etc.

Therapeutical approaches/models

- Muscle reeducation
- Facilitation
- Task-oriented

Neurofacilitation approach

Task-oriented approach

in neurophysiotherapy/rehabilitation

Neurofacilitation approach

- Based on reflex and hierarchical models of motor control

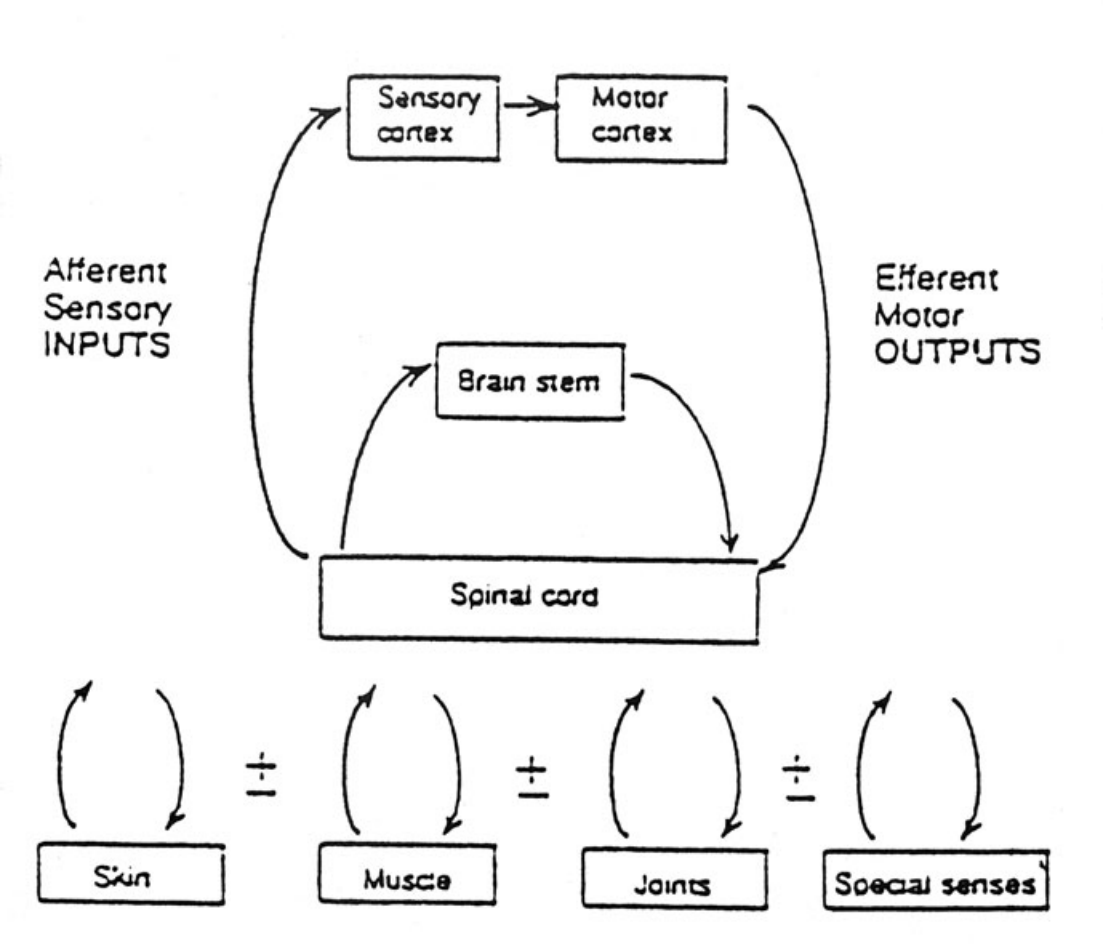
Reflex model of motor control

Reflex model of motor control

- It is based on the classic experiments of Sherrington (1906, 1947) and Magnus (1925, 1926)
- Reflexes - stereotyped responses to sensory input
- They are considered the basis for all movements
- The unit reaction of nervous integration is the reflex
- Coordination is the compounding of reflexes
- Chain of reflexes (at spinal, brain stem and cortical areas) result in normal movement

- Movement – summation of reflexes
- Reflexes reflect motor control

Reflex model od motor control (Horak, F.B.,1991)



Reflex model of motor control

- Afferent sensory inputs are necessary prerequisite for efferent motor outputs
- Sensory inputs control motor outputs
- Motor control comes from peripheral parts of NS
- NS is a passive recipient of sensory stimuli that triggers, coordinates and activates muscles that excite more sensory systems that in turn activate more muscles

- „Peripheralist“ view of motor control

Reflex model of motor control – clinical implications

- By identification the entire set of reflexes acting in a patient

  PT examines/evaluates patient´s motor control and predicts the quality of his motor function
- By appropriate stimulation PT elicits stereotyped and „proper“ reflex responses (turning the head – elicits neck reflex response, by tipping a tilt board –righting rr.))
- In therapy PT stimulates „good“ reflexes (that cause normal movement) and inhibitis „bad“ reflexes (that interfere with normal movement)

  (child prone over the ball – inhibition of tonic extensor and neck rr, facilitation of normal righting and equilibrium rr)

The limitations of the reflex model

- Deafferented animals show coordinated movements (experiments)
- 2 important concepts were not incorporated – feedback and feedforward system/control

- Described/explained in engineering model

Engineering model of motor control

Well described by Miall (1995) who explains:

- Motor system has to solve problems in response to changing sensory inputs, internal goals or errors in performance

Motor system needs to:

- select an appropriate action,
- transform control signals from sensory to motor frameworks,
- coordinate the selected movement with other ongoing behaviours and postural activity,
- then monitor the movement to ensure its accuracy and efficacy

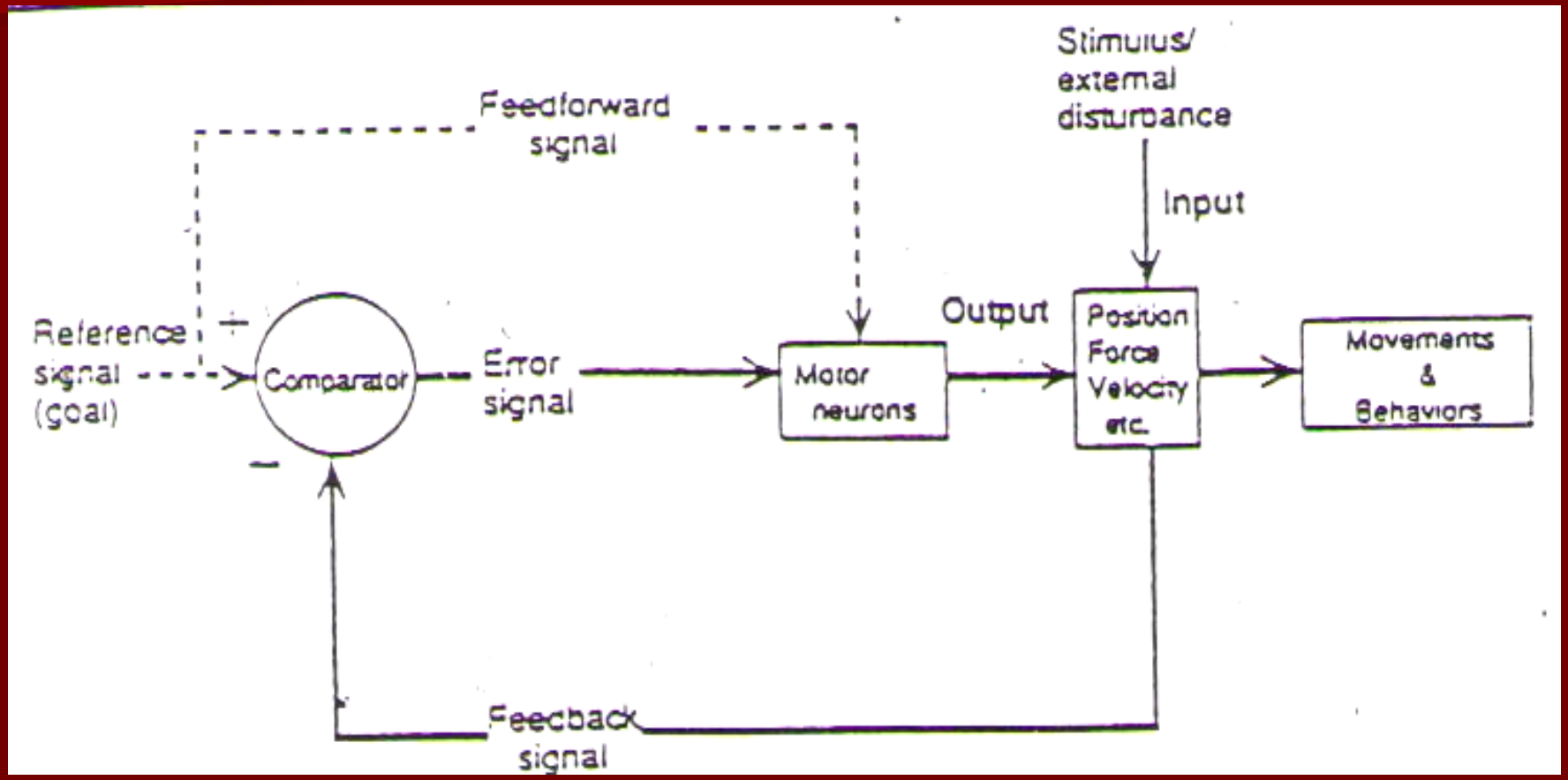
Engineering model of motor control

- Useful for understanding how the NS can be both proactive and reactive
- Proactive – NS produces activity on the basis of past performance and knowledge of outcome (*most movements are iniciated before any sensory stimulus, e.g. postural muscle activation*)
- Reactive – NS ensures that the task is executed as required in the context of the changing internal and external environments (*can correct performance by comparing the expected and actual outcome of a movemet strategy)*

- Assumes that the CNS acts in a linear way

- There are some limitations when applied to brain lesions
- Feedback systems (necessary for skill learning) are slow

Engineering model (Horak, 1991)



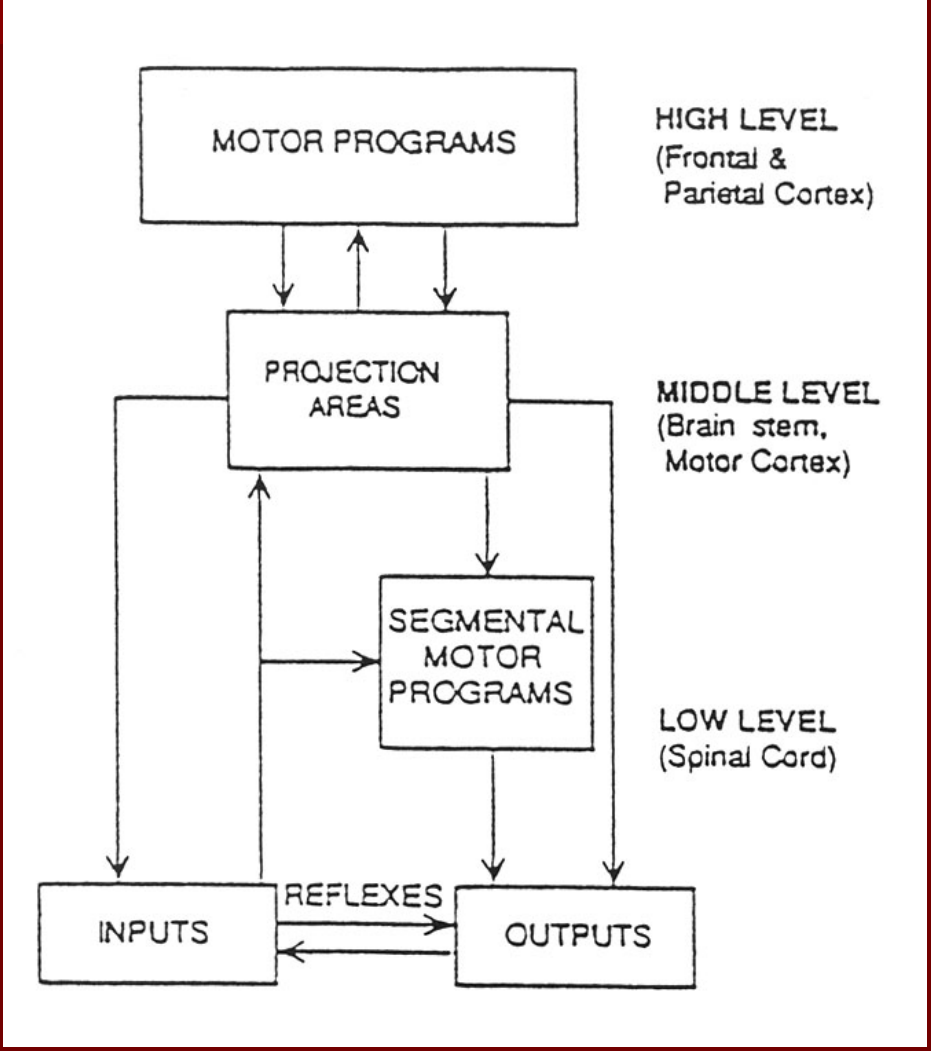
Hierarchical model of motor control

Hierarchical model of motor control

- First articulated by Sir Jackson (1932)

- Still forms the basis of clinical neurology today
- Control of movement is organized hierarchically
- From the lowest levels in the spinal cord, to intermediate levels in the brain stem, to highest levels in the cortex
- „centralist“ view in which normal movements are driven by motor programmes that specify muscle activation patterns
- Reflexive movements only dominate after injury to higher centres as a result of lack of higher-level control onto lower-level (primitive reflexes)

Hierarchical model of motor control (adapted from Phillips, Porter, 1977)



Hierarchical model of motor control

- Clearly separates high-level, (voluntary control) and low-level (reflexive, automatic control)
- Voluntary movements initiated by the will, with specific goals in mind, manifested in an infinite variety of forms
- Reflex movements initiated by sensory stimuli in a fixed relation between the intensity and form of the stimuli and the intensity and form of the response

More recent view of hierarchical model

- Many levels of control – from the most automatic (at the lowest level) to the least automatic (at the highest levels)
- Complex motor control – information from lower levels can affect higher levels

Clinical implications of hierarchical model

- In NS lesions – high-level control of lower-level is disrupted => primitive reflexes then dominate movements
- When primitive reflexes are released, higher-level coordinated movement patterns are „blocked“, the normal differentiation of the movement is disturbed

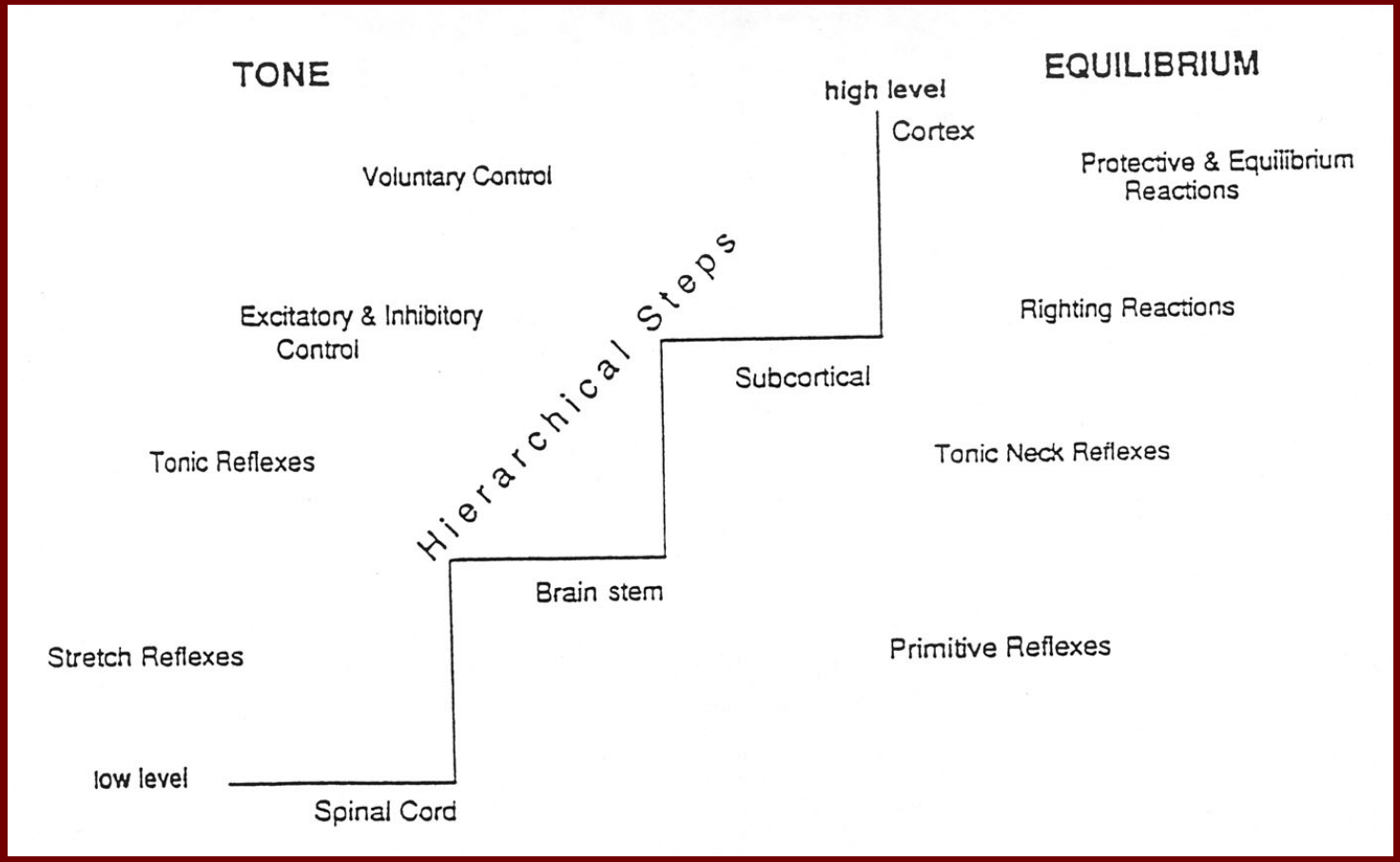
Reasonable goal for therapeutic intervention is :

- to idetify and to prevent primitive reflexes to take over (e.g. to eliminate dominance by tonic reflexes so that higher-level, equilibrium reactions can be in control)
- and to reduce hyperactive stretch reflexes so that the higher-level coordinated movements are allowed

Clinical implications of hierarchical model

- The stepwise levels of control in a hierarchy imply a stepwise sequence of motor recovery and motor development from lower levels to higher levels
- During maturation the infant begins to inhibit primitive reflexes (the most immaturate responses) and to develop righting and later on equilibrium reactions
- The development of both muscle tone and postural equilibrium described as steplike stages from primitive, spinal level control to mature, cortical control

Stepwise levels of control of muscle tone and equilibrium (hierarchical model) Horak 1991



Clinical implications of hierarchical model

- Treatment progresses from the most automatic, lower levels controled by therapeutic sensory stimulation
- To the least automatic, higher levels voluntarily controlled, such as skilled tasks
- PT aims to help patients move out of low-level, stereotyped patterns to high-level control of individual joints nad muscles

- Model is useful in identification of the location of neural lesions and helps the prediction of recovery

Limitations of the hierarchical model

- Motor development does not follow a stepwise progression
- Very sophisticated, coordinated locomotor movement patterns (walking) do not require control from the top down
- There is no clear distinction between voluntary and reflex/automatic control
- Every volitional movement is associated with automatic synergistic activity and postural adjustments
- Many volitional actions are adjusted automatically by sensory feedback and volition can influence reflex responses to stimuli
- Muscle activaton patterns are not always correlated with characteristic kinematic patterns of movement
- The brain is not able to specify in the NS every unique muscle activation pattern for every movement a person will ever generate

Hierarchical model

- Is considered outdated
- It is not useful to think of higher centres controlling lower centres
- But it still has some value – the effect of the cortex on the control of movement

- There is a considerable control of the cortex over the spinal cord and its action with subcortical areas in the selection, planning and execution of motor commands (Winstein 1997)

Cortical control - departure from the traditional view

- The cortex, traditionally associated with the control of skilled voluntary movements
- But is also active during more automatic activities such as swallowing (Hamdy et al 1998) and locomotion (Capaday et al 1999)
- Spinal cord is capable of producing motor activity without any inputs from supraspinal centres (Grillner 1985, Rossignol et al 1988, central pattern generators)
- Cortex can generate command without feedback from the periphery

- On the other hand fine finger movements of the hand are largely under cortical control

Facilitation model in physiotherapy

based on hierarchical and reflex model of motor control

Facilitation model/approach

- In the 1940-50s developed by Kabat, Knott and Voss, Brunnstrom, Rood, Petö, Bobaths
- NS lesions result in a lack of higher-level control over movements and a release of primitive and abnormal reflexes at lower levels
- E.g. in cerebral palsy the lesion results in lack of inhibition, in primitive total patterns, in insufficiently developed postural reflex mechanisms
- Abnormal movement patterns are the direct result of the neural lesions

Facilitation model/approach

- NS can control movements more effectively if it experiences normal movement patterns guided by skilled therapist

- NS can learn abnormal as well as normal movement patterns => do not begin functional activities to early

  => abnormal, compensatory patterns may become fixed

Facilitation model/approach

The aim of the therapy is:

- Inhibition of abnormal tone and primitive reflexes
- Facilitation of normal movement patterns
- Provision of an appropriate proprioceptive feedback with hands - on approach of guiding movement patterns (handling)
- Also cutaneus, vestibular, vibratory, temperature stimuli are used
- Therapeutic intervention starts at the lowest level by stimulating reflex responses
- and progresses to automatic responses and then to voluntary isolated (selected) movements

Limitations of the facilitation approach

- 1. The lack of carry over of the facilitated normal movement patterns into functional activities of daily living
- Difficulty to convince patients to work on movement patterns isolated from the functional tasks (human beings are motivated by functional, task goals)

- 2. Patients are often passive recipients of the therapy
- NS is passively awaiting modification by the therapist instead of active working to determine its own preceptions and actions
- (passive experience is not equivalent to actively driven sensory experience for neural plasticity)

- *Motor learning: skills better accomplished by practising the very goal-directed task with regular cognitive information regarding knowledge of result*
- *rather than by passively observing others or by practising small components of the movement pattern in isolation from the task itself*

Limitations of the facilitation approach

- 3. Doesn´t not take into account the musculoskeletal conditions that influence the motor performance (limited ROM, decrease of muscle strength, postural alignment, pain)
- as well as environment conditions; patients need to control their movements also in nonclinical environments and without therapist´s hands

  => doesn´t not consider the combined effects of neural and nonneural limitations and the patient´s ability to compensate for the lesion
- 4. normal movement patterns are not automatically released as a result of the inhibition of abnormal tone and primitive reflex patterns

Continuation of outdated ideas in practice

(Mayston, 2001)

- Emphasis on reflex activity as a basis of tone and postural activity
- Emphasis on the inhibition of spasticity
- Overemphasis on the significance of righting and equilibrium reactions

Systems model of motor control

Systems model of motor control

It has its origin in the work of N. Bernstein (1932, 1967 transl.)

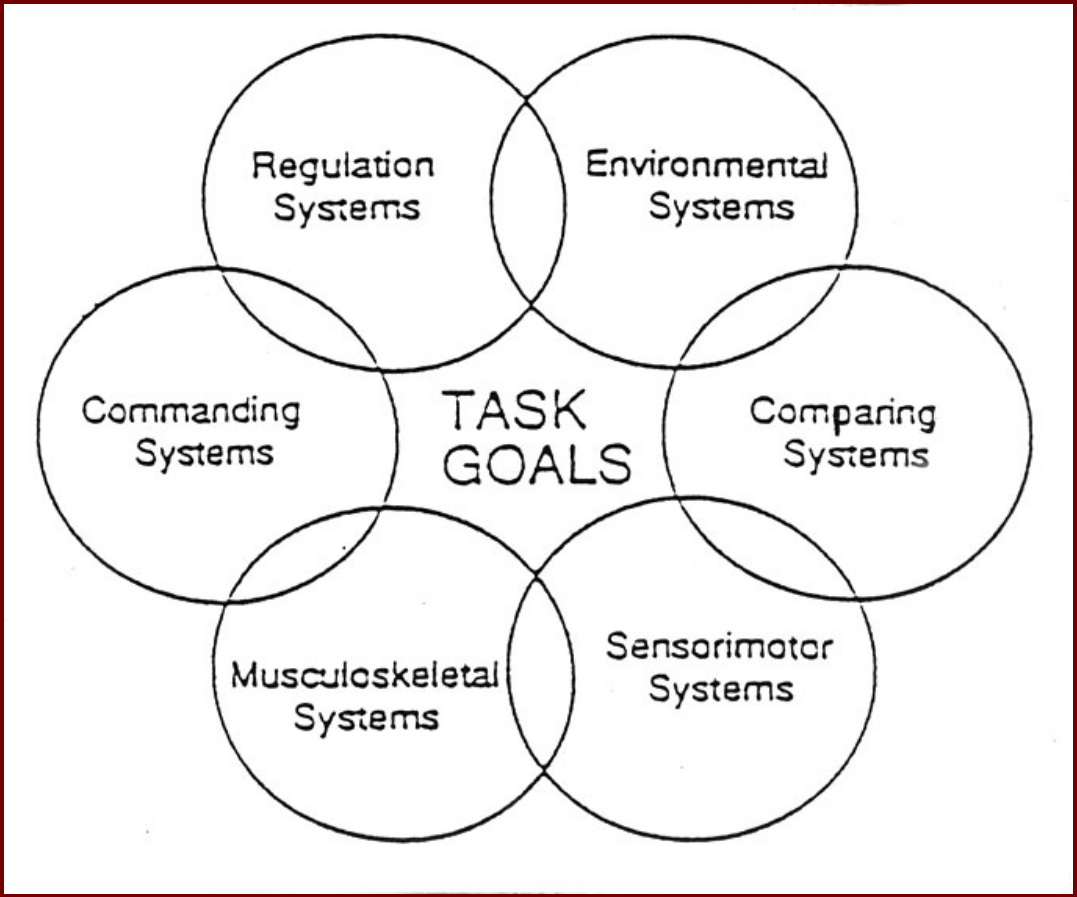
He suggested that:

- The control of movements was distributed throughout several cooperative and interactive systems, each of them contributes to different aspects of motor control
- *(Movements are not peripherally or centrally driven, there are no levels of lower and higher control)*
- We have many degrees of freedom (many joints and movements)
- =>in order for coordinated movement to occur muscles are activated together in synergies such as locomotor, postural, respiratory

Systems model of motor control

- Movements are organized around a functional goal
- Movements are achieved by the interaction of multiple systems such as the senzorimotor and musculoskeletal systems and the system of environment
- The importance of the interaction between the individual and the environment is emphasised

Systems model of motor control (F. Horak 1991)



Systems model of motor control

- Normal movements are coordinated through strategies which emerge from interaction of different systems (X through muscle activation patterns or by central programmes)
- Abnormal motor control results from impairments in one or more of the systems which control the movement
- Functional goals are achieved by activity of the remaining systems, which are doing the best they can
- The role of sensation is important not only for adaptive control of movement but also for the predictive one

Systems model of motor control

- NS is organized to control the accomplishment of task goals
- NS adapts to and predicts constraints placed on the movement by musculoskeletal system and environment
- NS by continually comparing anticipated and actual interactions with the world constantly modifies its model to realize the most effective and efficient means to accomplish task goals
- CNS operates in a task/goal directed way using a motor learning approach (Carr&Shepherd 1998)

Limitations of the systems model

- There are other models that include assumptions of the systems model (ecological approach, dynamic action theory,..)
- There is no consensus on terminology and definitions of terms
- Because the model is abstract and motor control is so distributed – it is difficult to relate individual theoretical component systems to neuroanatomy
- Thus it is difficult to test the model with the traditional approach (experiments on animals)

Task-oriented approach

based on reflex, hierarchical
and
systems model of motor control

Task – oriented approach

- It targets both peripheral (musculoskeletal, environmental systems) and central system
- Both functional goals nad environmental conditions/constraints play a major role in determining movement
- A clinical advantage of this model – it can account for the flexibility and adaptability of motor behaviour in a variety of environmental conditions

Task - oriented approach

- Given the assumption that movements are organized around behavioral goals (goal-directed, functional behaviour)

  => one of the major aims is to accomplish goals for functional tasks

  => to work on specific functional tasks (x on eliciting reflexes or motor patterns)

Task - oriented approach

Given the assumption

- that NS is adapting continually and dynamically to its environment and musculoskleletal system
- that normal movement strategies represent appropriate interaction with musculoskeletal and environmental conditions

=> PTs assess and manipulate those systems/conditions they practice tasks in a variety of postures, under varying surface, visual and biomechanical situations to achieve efficient, purposeful motor behaviors

Task-oriented approach

- Voluntary motion uses many different synergies according to changing environmental situations

  => PTs teach the NS/patient how to solve different motor problems by practicing tasks in a wide variety of environments

- The NS seeks to accomplish important behavioral goals with whatever systems remain

  => PT´s task is to identify, improve and develop useful compensatory strategies (and discard less useful, less efficient)

Task-oriented approach

- NS is not a passive recipient of the stimuli (actively seeks its own perceptions and actions)
- =>the patient must actively and voluntarily practice motor performance motivated by the goal to accomplish specific tasks

- PTs provide verbal infomation (incl. info about results)
- Sensory feedback is provided from every possible source, incl. proprioceptive, cutaneous, auditory and visual sources

Task – oriented approach

Therapeutic aims (Horak 1992, Mayston 2002))

- Practice ability to achieve task goals
- Teach motor problem solving (ie. adaptability to contexts)
- Learn strategies to coordinate efficient and effective behaviors, effectively perform functional tasks
- Develop effective and efficient compensatory strategies
- Use musculoskeletal and environmental constrains

  =>
- PT helps the neurologicaly impaired person to problem-solve the achievement of a task goal rather than to learn movement patterns

Clinical limitations of task-oriented approach

- For many PTs – reduced emphasis on hands-on approach and the increased emphasis on cognitive information provided to patient
- Patients with severe neurological impairment (especially cognitive) will not be able to make good use of cognitive info X the great psychological power/effect of a „healer´s“ touch

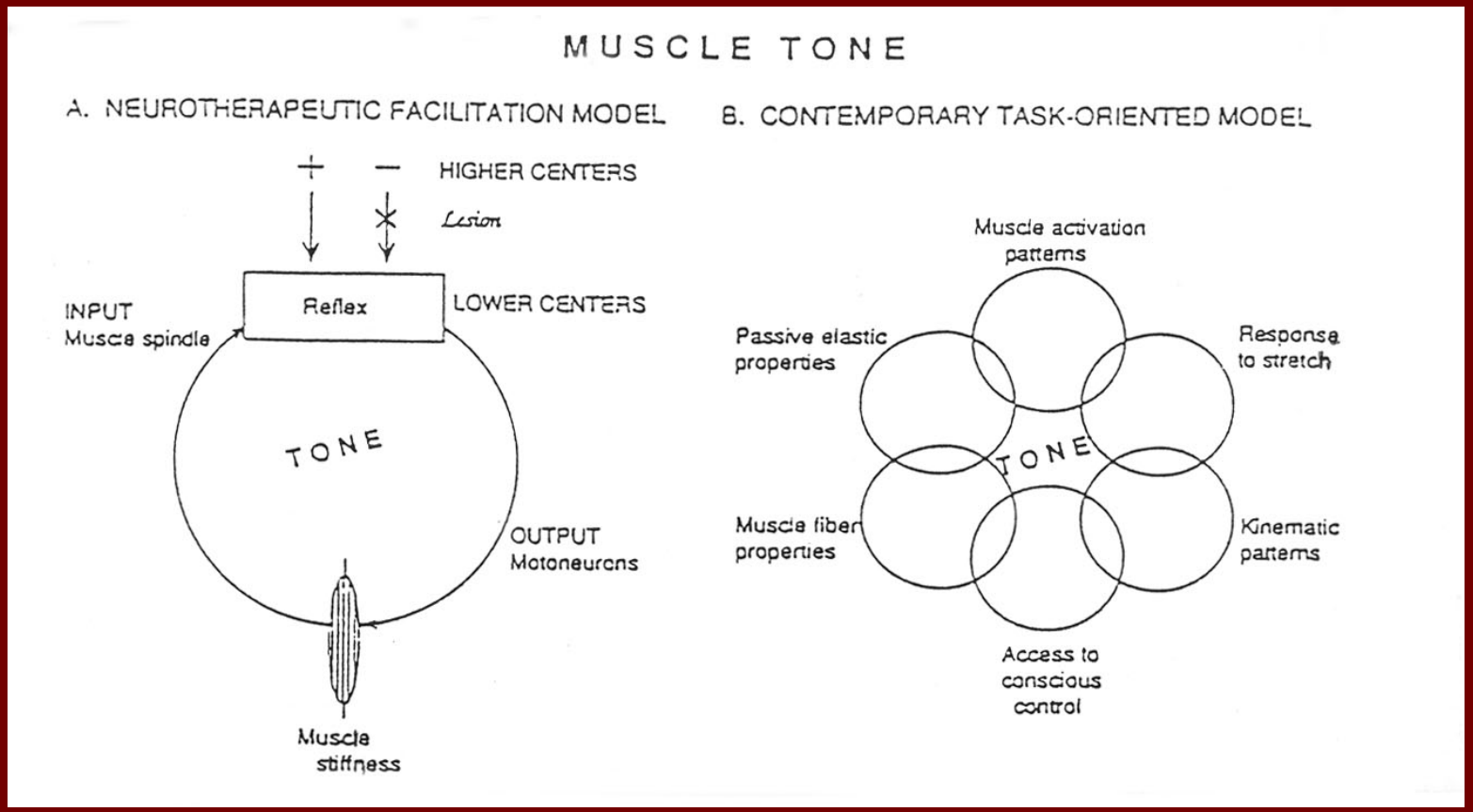
Difficult:

- to identify and evaluate the contribution of each system
- to quantify effective, efficient compensations
- to provide time-consuming practice of skills

- Major limitation – the approach identifies many more motor control problems than there are specific therapeutic „excercises“ developed to treat those problems

Therapeutic approach to muscle tone (Horak 2002)

A. Neurotherapeutic Facilitation Model
B. Task-oriented Model



Facilitation approach to muscle tone

- Exccesive muscle tone /spasticity is due to lack of inhibition of higher centres on the now over-responsive stretch reflex
- This excessive tone blocks normal coordinated movement
- How can I best reduce tone in my patient?
- Once the pattern of abnormal tone is identified therapeutical intervention involves using the proprioceptive system to reduce tone and facilitate normal movements

Task-oriented approach to muscle tone

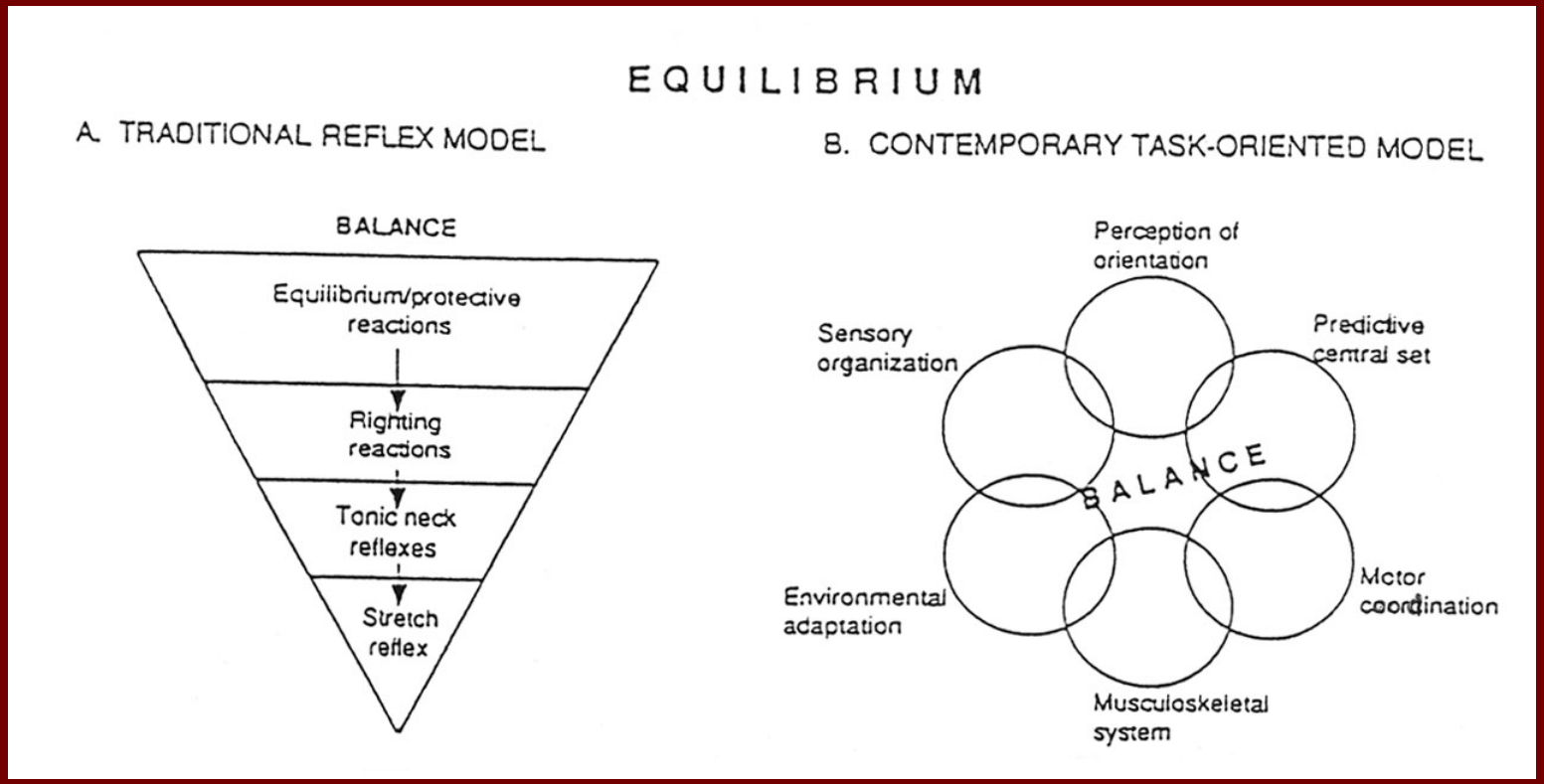
- Views spasticity as a set of motor behaviors that results as an emergent property of many inreacting systems, any of which may be disordered
- Which combination of systems (muscle activation patterns, kinematic patterns, response to stretch, conscious control of muscle activaton, muscle fiber properties, passive elastic elements) are abnormal and limit optimal motor performance?
- Is the spasticity a primary result of neural lesion or a secondary compensatory strategy that allows cetrain functional behavior?
- After this problem solving process PT decides which disordered components can be changed by therapeutical intervention and how they can help the patient to find efficient, effective movement strategies

Tone and techniques of handling (Mayston 2002)

Abnormal postural tone	*Handling technique*	*Aim of use of technique*	*Comment*
Released tonic reflexes (1940s)	Reflex inhibiting postures (RIPs)	Inhibition of released tonic reflexes	Static – little or no movements; often opposite to pattern of spasticity
Abnormal tonic (postural) reflex activity (1960s)	Reflex inhibiting patterns (RIPs)	Simultaneous inhibition, facilitation & stimulation	Emphasis on facilitation of postural reactions
Abnormal neural and non-neural aspects of tone (1990 – present)	Tone influencing patterns (TIPs)	'Inhibition', facilitation, stimulation and biomechanical influences	Influence both the control of posture and task performance

Therapeutic approach to equilibrium/balance (Horak 2002)

A. Neurotherapeutic Facilitation Model
B. Task-oriented Model



Facilitation approach to balance

- Postural equilibrium is maintained by reflex mechanisms organised hierarchically within the NS
- Poor balance is thought to result from an abnormal postural reflex mechanism in which lower level primitive postural reflexes (stretch reflex, tonic neck reflexes) dominate and block higher-level equilibrium reactions
- Therapist asks which postural reflexes are present or absent
- Treatment is aimed at inhibiting inappropriate, primitive postural reflexes and facilitating normal equilibrium reactions
- If appropriate responses are not observed – was the stimulus inadequate, the sensory system insensitive, reflexes inappropriately integrated?

Task-oriented approach to balance

- Normal postural motor behavior is a product of an interaction of many components organised around a fundamental behavioral goal – to maintain equilibrium and orientation in the environment
- Therapist asks what are the primary constraints limiting adequate control of balance
- Disorders of postural control result from constraints placed on the system from a multitude of sources
- Therapist asks – which combination of systems (sensory organisation, environmental adaptation, perception of orientation, motor coordination,..) are abnormal and limit postural behavior
- The therapy is directed at reducing or eliminating those constraints
- or helping patient to find effective strategies for postural control

There are some other models of motor control such as

Biomechanical

Neurophysiological

Neuroplasticity – the way forward

Biomechanical model of motor control

- Based on biomechanics, biomechanical principles
- Stressing the importance of muscle muscle strength, force production, movement velocity and muscle length
- There is a good evidence to support this model =>
- lack od force generation by paretic agonists as the major cause of reduced torque generation (Davis et al 1996)
- biomechanical properties of muscle as an important aspect of force production
- changes in the distribution of muscle fibre types also contribute to problems of force generation (Ito et al 1996)

Biomechanical model of motor control

- A muscle will produce optimal force at mid-range (maximal overlap of cross bridges can occur)
- Changes in muscle length affect the ability to generate sufficient force to achieve an efficient movement strategy
- Changes in muscle length also alter joint alignment which affect the ability to generate sufficient torque and efficient muscle activation patterns
- Possibly the inappropriate co-contraction of agonists and antagonists results from altered biomechanical alignment in addition to abnormal neural control of the reciprocal inhibitory circuits between the muscle pair (Woolacott&Burtner 1996)

Biomechanical approach in physiotherapy

Carr and Shepherd

- Primarily based their therapy on principles of motor learning and biomechanics
- Stressing the importance of muscle length, muscle strength, ROM
- Activation of appropriate muscle strategies in a task-specific context

- Also Bobath concept

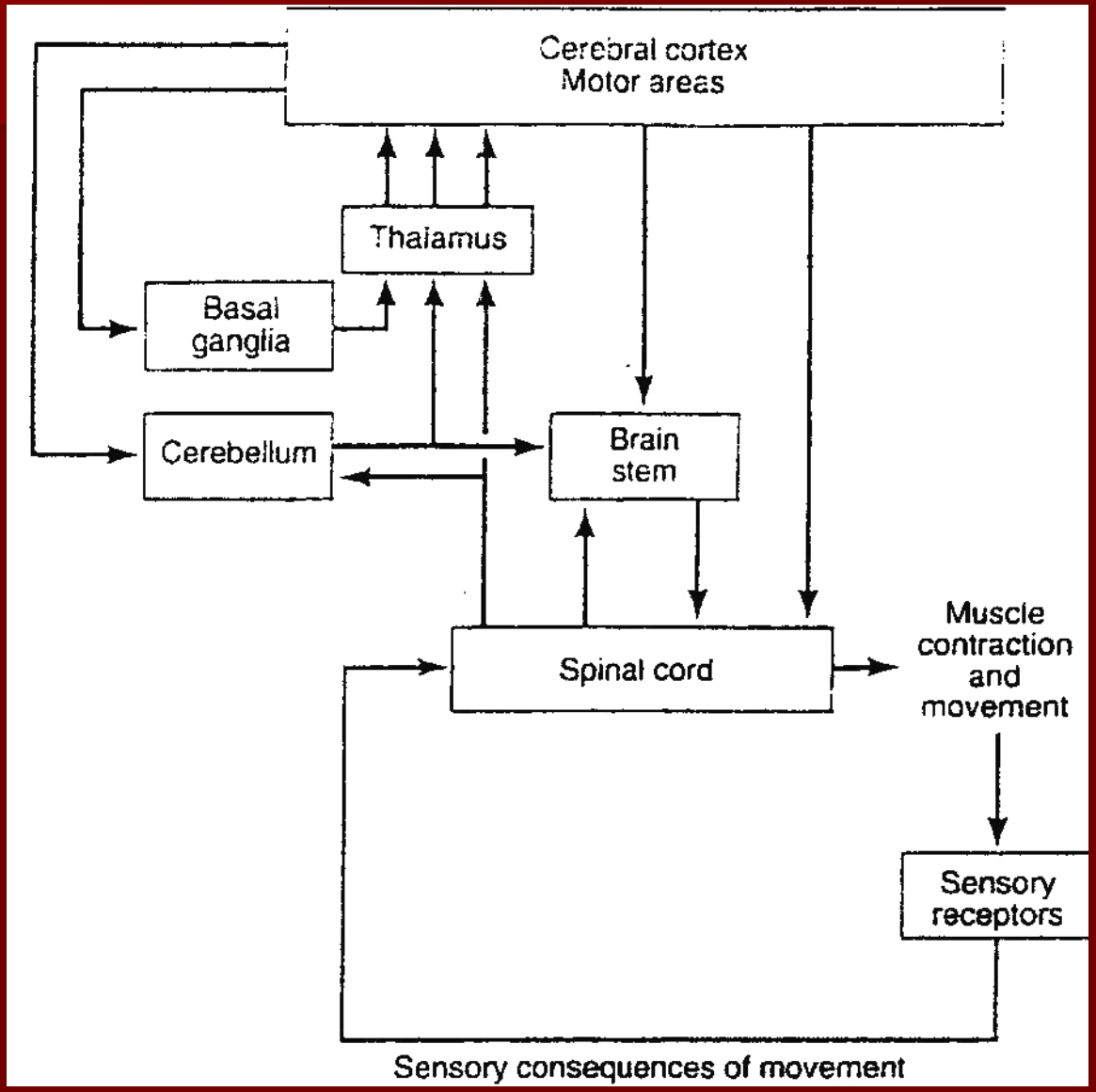
Neurophysiological model of motor control

- Helps to understand the interactions between various neural mechanisms, both central and peripheral

- Indicates in particular the importance of supraspinal mechanisms for the modulation of spinal systems

  to produce the required control of movement

Wiring – up diagram gives the idea how different parts of NS interact (Kandel et al 1991)



What should we know about neurophysiological control of movement?

- The presence of brain activity when simply imagining the movement
- The NS is largely proactive and not simply reactive (in response to sensory feedback)
- Central (feedforward) mechanisms are based on innate and ongoing experiences of the individual and can take place without any kind of sensory feedback
- Motor control is programme – based
- Central programming requires the integration of many neural structures, both supraspinal and peripheral

What should we know about neurophysiological control of movement?

Mayston, 2002

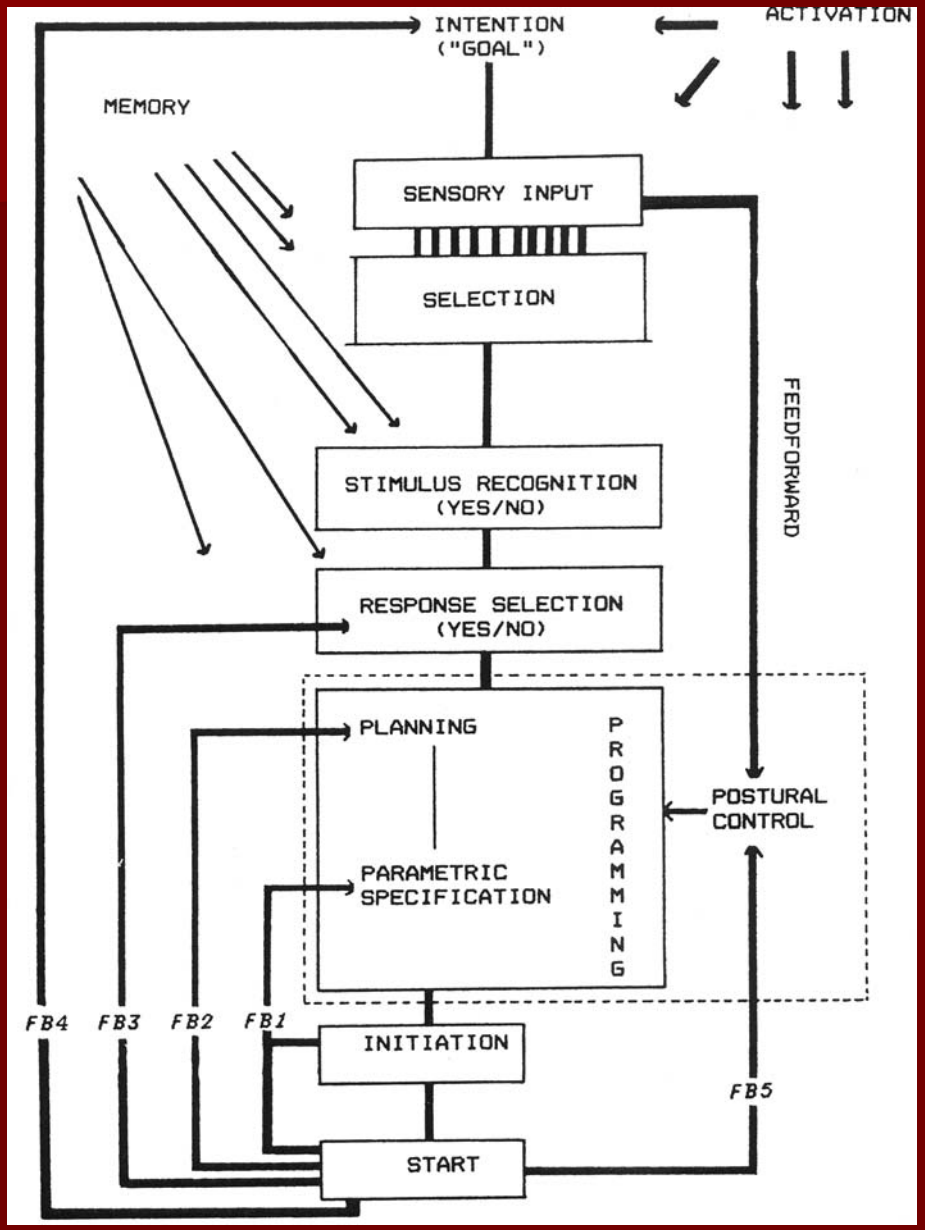
- Cerebellum is mostly concerned with processing of sensory information during an ongoing task
- Basal ganglia are more concerned with organisation of well-learned tasks
- CNS organises the required neural activity to perform a task on the basis of the past experience
- But, if prior knowledge is lacking, feedback systems will play a greater role (takes longer to effect a response)

What should we know about neurophysiological control of movement?

Several stages in the process of drinking from a cup

- Stimulus generated (internally, externally)
- On the basis of past experience CNS organises the required strategy to achieve a goal
- Essential are perceptual aspects (weight, shape, texture of the cup) – the correct grip and load forces have to be computed by CNS
- Spatial aspects are important for the grading and timing of postural adjustments and movements of the actual limb
- Oral and swalloving musculature need to be coordinated with breathing
- Decision also needs to be made when sufficient liquid has been ingested

Model of human motor control/behavior and learning (T. Mulder 1991)



What should we know about neurophysiological control of movement?

- Although sensory information is not necessary for tasks to occur
- It is important for the fine-tuning and learning of any motor/postural task
- „Deafferented man“ can perform the tasks previously experienced, in the same way
- but he needs to repeat and is not able to learn new skills
- Important when „training“ neurologically impaired patients with difficulties od sensory perception or sensory processing
- Result of the experiments: cortext plays a lesser role in simple well-practiced movements (power grip X fine grip)

What should we know about neurophysiological control of movement?

- Surface EMG recordings: changes in motor-unit synchronisation following stroke (Nadler at al 1999)
- Lack of reciprocal inhibition between antagonists demostrated in children with spastic cerebral palsy (Gibbs at al 1999)
- Problems with reciprocal innervation in adults with spasticity =>the reason for difficult movement is not excessive co-contaction
- But the inability to produce force in the agonist (Burbonnais, Van de Noven 1989, Davies 1996)
- Abnormalities in reciprocal innervation (reciprocal inhibition) seem to be significant in spastic children x spastic adults

Neuroplasticity model

- Plasticity underlies all skill learning and is a part of CNS function in healthy and brain-damaged individuals at any age (Leonard 1998)
- Imaging techniques (PET, fMRI) has provided evidence of the plasticity of the CNS
- Sensory stimulation (inc. behavioral training), if given effectively and often enough, can expand sensory areas of the cortex
- Plastic changes are demonstrated as a result of motor training - training a hand expanded the cortical areas represented by the muscles executing that task
- Training of a new motor skill in healthy adults demonstrated changes in senzorimotor function

Skill learning – how to do it?

Therapy programmes should be based on 3 principles (Winstein et al 1997):

- Practice is fundamental for motor learning and improving skill in both healthy and movement – impaired individuals
- Active participation +
- Active working are necessary
- => to achieve meaningful goals

- *Carr&Shepperd (1980, 87, 98) have proposed that the methods used in training of patients with CNS lesions could be similar to those, already shown to be effective in increasing motor skill in non-disabled persons*

Skill learning and Bobath concept

- These 3 principles can be enhanced by „preparation for function“ (from Bobath concept)
- 1. mobilisation of tight connective tissue and/or joints
- 2. elongating muscles to enable activity from a better biomechanical advantage, to achieve better body alignment for more efficient balance and muscle activation
- 3. practice of task-component parts to enable the patient to get the idea of the movemet required

- Practicing in a functional task which the patient wants to achieve (requires realistic goal setting)
- Handling – when given in a proper way and in a proper time - facilitates the normal movement and helps to achieve a normal function, very first step in treatment

Skill learning and Bobath concept (handling, quality of the movement ?)

- Preparation given as a treatment is of no value of its own
- Must be incorporated into useful activity
- What the neurologicaly impaired person can do with some assistance – that is their potential
- It is of little use to the patient if these potentially achievable skills can only be practiced with the therapist´s help
- But when required it is appropriate and important to give help – to enable the person to practice activities which are possible, with a little help, to achieve independently
- It is of no use to the patient to be prevented from trying to practice activities because there is a danger of increasing spasticity
- Early training will enable less secondary loss of cortical tissue and thus enable greater possibilities for recovery (Nudo et al 1996)

Conclusions

- Successful performance of a senzorimotor task requires the integrated action of the CNS
- No one model is sufficient for the therapist to apply a problem-solving approach to the management of the neurologicaly impaired person
- The musculoskeletal system is critical to the execution of the motor command in addition to various cortical and subcortical areas involved in the organisation of the task

Conclusions

- The terapist must understand the nature of the movement disorder
- to employ effective treatment strategies
- and to set appropriate goals for those patients
- => to maximise the potential for functional independence

(Mayston 2002, 2008)

???

- We use at least some principles of all the models of motor control mentioned here
- But still we are not sure whether our therapy is the most efficient and effective one
- What to do?

In the future

- There is a urgent need for an integrated approach to neurophysiotherapy that is not based on approaches, but rather is client based with a sound theoretical, and where possible, evidence base (Mayston, 2008)

Physiotherapy

- Profession of „skilled hands“ and problem solvers
- Specializing in the techniques and approaches of physiotherapy is not enough
- We have to specialize in the problems of our patients

Some questions

- Which therapy approach?
- Are we managing spasticity, hypertonia, stiffness (contracture)?
- What „inhibition“ means? Are co called inhibitory techniques relevant?
- What „facilitation“ means?
- What is the postural control, balance? How to train it?
- What is ment by „compensation, compensatory movement strategies?
- Associated reactions – another example of confusion in neurophysiotherapy
- Terms which have different meaning for therapists, neurologist and scientists