



MOTOR CONTROL: ISSUES & THEORIES

SU 1.1 – CHAPTER 1 P3-20 - HMSB 112

LEARNING OUTCOMES

- Define motor control, & discuss its relevance to the clinical treatment of patients with movement pathology
- Discuss how factors related to the individual, the task & the environment affect the organization & control of movement
- Define what is meant by a theory of motor control & describe the value of theory to clinical practice

LEARNING OUTCOMES

- Compare & contrast the following theories of motor control: reflex, hierarchical, motor programming, systems, dynamic systems, & ecological, including the individuals associated with each theory, critical elements used to explain the control of normal movement, limitations & clinical applications
- Discuss the relationship between theories of motor control & the parallel development of clinical methods related to neurologic rehabilitation
- Compare & contrast the neuro-facilitation approaches to the task-oriented approach w respect to assumptions underlying normal & abnormal movement control, recovery of function &, clinical practices related to assessment & treatment



INTRODUCTION

WHAT IS MOTOR CONTROL?

- Movement = critical aspect of life
- Essential for ability to – walk, run, play, seek out & eat nourishing food, communicate & earn a living *THUS* survival
- **Field of motor control directed at: studying the NATURE OF MOVEMENT & HOW MOVEMENT IS CONTROLLED**
- **MOTOR CONTROL = THE ABILITY TO REGULATE or DIRECT MECHANISMS ESSENTIAL TO MOVEMENT**



WHAT IS MOTOR CONTROL?

- Addresses the following questions:

- 1) How does CNS organize the many individual muscles & joints into coordinated functional movements?
- 2) How is sensory information from the environment & body used to select & control movement?
- 3) How do our perceptions of ourselves, the tasks we perform & the environment in which we are moving influence our movement behaviour?
- 4) What is the best way to study movement?
- 5) How can movement problems be quantified in patients with motor control problems?

WHY SHOULD THERAPISTS STUDY MOTOR CONTROL?

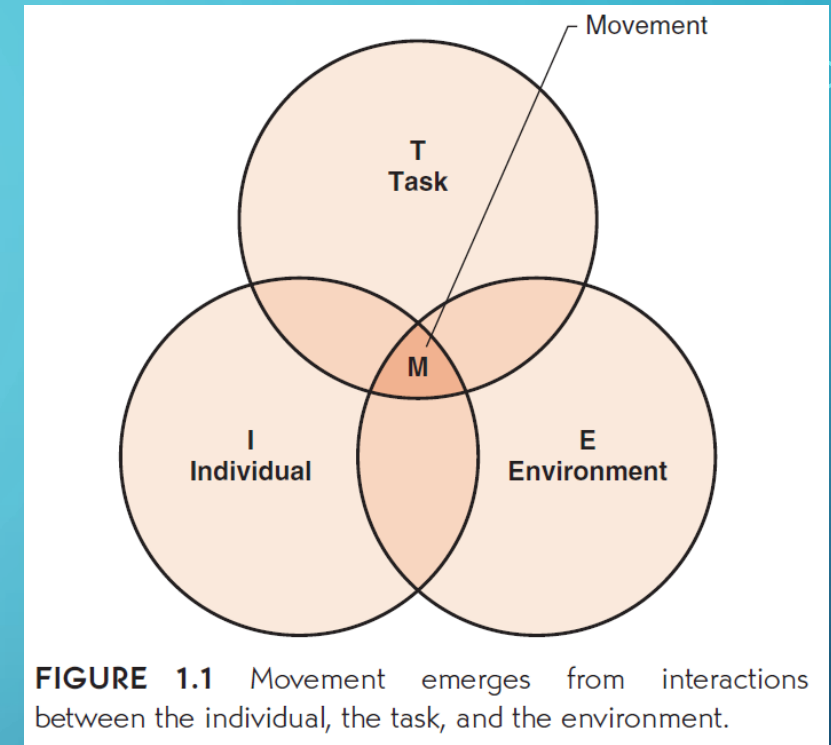
- Assessment & Treatment of movement disorders depend on a number of factors:
 - knowledge of the neural basis for normal movement control & pathophysiology of impaired movement
- Assessment & Treatment strategies must be consistent with: current knowledge regarding the neural basis for movement disorders
- Therapeutic strategies are designed to: improve the **QUALITY** and **QUANTITY** of postures & movements essential to function
- Thus understanding motor control & the nature and control of both normal and abnormal movement is critical to clinical practice

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UNDERSTANDING THE NATURE OF MOVEMENT

Movement emerges from interaction of 3 factors:

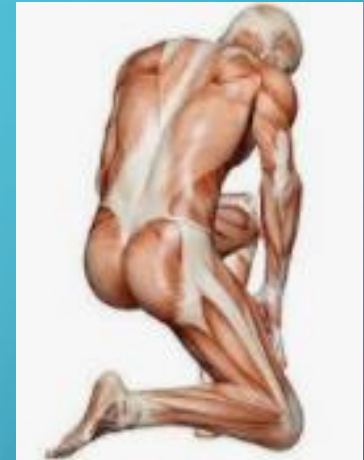
1. The individual - generates movement
2. The task – to meet demands of task being performed
3. The environment – within a specific environment



- The organization of movement is constrained by factors within these 3 factors
- A person's functional capacity is determined by: the individual's capacity to meet interacting task & environmental demands
- Motor control research focussing only on processes within the individual without taking into account the environment & task – incomplete picture

INDIVIDUAL SYSTEMS UNDERLYING MOTOR CONTROL:

1. MOTOR/ACTION SYSTEMS



- Motor systems includes: neuromuscular & biomechanical systems
- They contribute to functional movement control
- Body is characterized by a high number of muscles & joints
- All must be controlled during execution of coordinated functional movement
- Multiple ways a movement can be carried out
- The degrees of freedom problem: The problem of choosing among equivalent solutions & then coordinating the many muscles and joints involved in a movement
- Major issue
- THUS – the study of motor control includes the study of the motor systems that control functional movement

Degrees of Freedom Problem

- Degrees of freedom (df) = Number of independent elements in a system and the ways each element can act
- Degrees of freedom problem = How to control the df to make a complex system act in a specific way
 - e.g. The control of a helicopter's flight (described in the textbook)
- Degree of freedom problem for the control of movement:
 - How does the nervous system control the many df of muscles, limbs, and joints to enable a person to perform an action as intended?

INDIVIDUAL SYSTEMS UNDERLYING MOTOR CONTROL:

2. SENSORY/PERCEPTUAL SYSTEMS



- Sensation & Perception = essential to the control of functional movement
- Perception – integration of sensory impressions into psychologically meaningful information
- Involves (a) peripheral sensory mechanisms & (b) higher-level processing that adds interpretation & meaning to incoming afferent information
- Sensory/Perceptual systems provide information about:
 - the state of the body (position of different body parts in space)
 - features within the environment, critical to the regulation of movement
- Integral to ability to act effectively within an environment
- Understanding movement requires study of systems controlling sensation & perception and their role in functional movement control

INDIVIDUAL SYSTEMS UNDERLYING MOTOR CONTROL:

3. COGNITIVE SYSTEMS



- Movement usually not performed without intent
- Therefore cognitive processes are essential to motor control
- Include: attention, planning, problem solving, motivation & emotional aspects of motor control that underlie the establishment of intent or goals
- Motor control includes perception & action systems organized to achieve specific goals or intents
- Study of motor control must include study of cognitive processes as they relate to perception & action

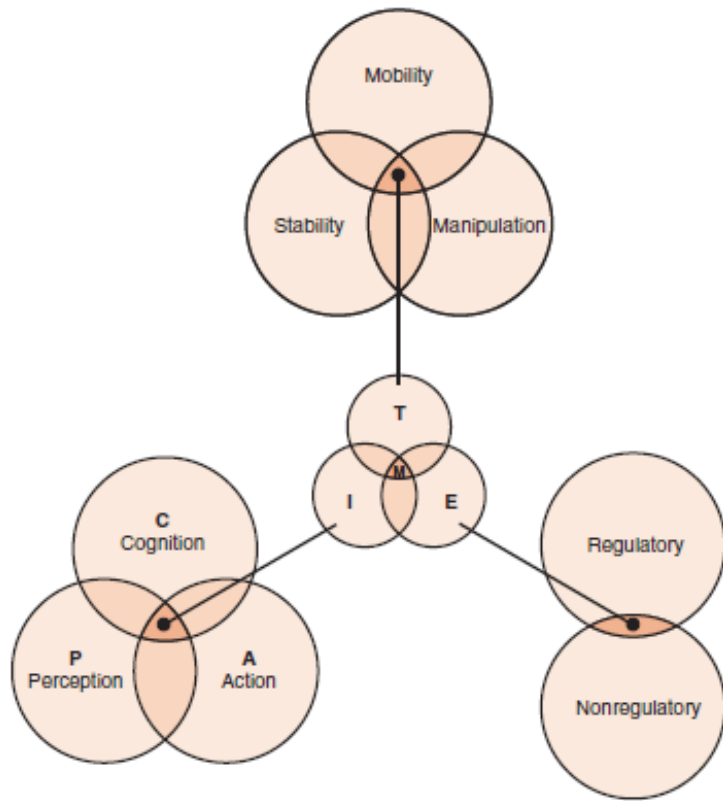


FIGURE 1.2 Factors within the individual, the task, and the environment affect the organization of movement. Factors within the individual include the interaction of perception, cognition, and action (motor) systems. Environmental constraints on movement are divided into regulatory and nonregulatory factors. Finally, attributes of the task contribute to the organization of functional movement.

- Within the individual many systems interact in the production of functional movement
- These systems are categorized as:
sensory/perceptual (S/P)
cognitive (C)
motor/action (M/A)
- These systems can be studied in isolation BUT
- A true picture of the nature of control cannot be achieved without a synthesis of information from all three

TASK CONSTRAINTS ON MOVEMENT CONTROL:

- Tasks can also place constraints on neural organization of movement
- Nature of task being performed in part determines type of movement needed
- Recovery of function following CNS damage requires: that the patient develop movement patterns that meet the demands of functional tasks in the face of sensory / perceptual, motor and cognitive impairments
- Therapeutic strategies that help the patient (re)learn to perform functional tasks , taking into consideration underlying impairments = essential to maximizing the recovery of functional independence
- WHAT TASKS? IN WHAT ORDER? AT WHAT TIME?
- **Understanding task attributes can provide a framework for structuring tasks**



- An understanding of task attributes can provide a framework for structuring tasks into a taxonomy
- Tasks can be sequenced from least to most difficult based on their relationship to a shared attribute
- In clinical environment tasks are often grouped into broad functional categories: bed mobility tasks, transfer tasks, ADLs or IADLs (work, housekeeping, money management)
- Tasks can also be classified according to critical attributes that regulate neural control mechanisms

TABLE 1.1 A Taxonomy of Tasks Combining the Stability–Mobility and Closed–Open Task Continua

	Stability	Quasimobile	Mobility
Closed predictable environment	Sit/stand/ nonmoving surface	Sit to stand/kitchen chair w/arms	Walk/nonmoving surface
Open unpredictable environment	Stand/rocker board	Sit to stand/Rocking chair	Walk on uneven or moving surface

TASK CONSTRAINTS ON MOVEMENT CONTROL

- Type of task being performed – great impact on neural organization of movement
- **Classified based on movement variability**

OPEN MOVEMENT TASKS:

- playing soccer / tennis
- require performers to adapt movement strategies to a constantly changing & often unpredictable environment
- Requirements: constant monitoring of sensory inputs
- Above are used to update, modify & regulate motor output



CLOSED MOVEMENT TASKS: *performed prior to open movement tasks*

- Relatively stereotype with little variation
- Performed in relatively fixed / predictable environments
- Less dependant on constant monitoring of sensory inputs related to environmental changes



TASK CONSTRAINTS ON MOVEMENT CONTROL

- Discrete / Continuous

DISCRETE MOVEMENT TASKS:

- kicking a ball, moving from sitting to standing or lying down
- **recognizable beginning and end**

CONTINUOUS MOVEMENT TASKS:

- walking / running
- **end point** of the task is not an inherent characteristic of the task
- is **decided arbitrarily by the performer**



TASK CONSTRAINTS ON MOVEMENT CONTROL

- Classified according to base of support: BOS still or in motion?

STABILITY TASKS:

- sitting / standing
- performed with **non-moving BOS**

MOBILITY TASKS:

- walking / running
- **Moving BOS**



PRACTICAL APPLICATION: Stability tasks practiced prior to mobility

Stability requirements are less demanding in tasks with a non-moving BOS

Attentional resources increase as stability demands increase

Tasks with lowest attentional demand = non-moving BOS – static postural control tasks

Attention demand increase in mobility tasks such as walking & obstacle clearance

TASK CONSTRAINTS ON MOVEMENT CONTROL

- Classified according to presence of manipulation component
- Addition of a manipulation task increases the demand for stability beyond that for the same task lacking the manipulation component
- Manipulation tasks involve movement of the upper extremities
- Tasks might be sequenced in accordance with the hierarchy of stability demands with or without manipulation e.g.

Standing

Standing and lifting a weight

Standing and lifting a heavy weight



ENVIRONMENTAL CONSTRAINTS ON MOVEMENT CONTROL

- Tasks are performed in a wide range of environments
- Movement are thus not only constrained by attributes of the task but also by the environment
- **For functionality the CNS needs to consider the attributes of the environment when planning task-specific movements**
- Attributes of the environment affecting movement can be divided into:
 - 1) Regulatory features
 - 2) Non Regulatory features
- Environmental features can:
 - Enable / support performance: walking in well lit environment
 - Disable / hinder performance: walking in dark environment



REASON: ability to detect edges, sizes of small objects & other surface properties
Planning effective intervention requires an understanding of features within the environment that regulate & affect performance of movement tasks

REGULATORY FEATURES

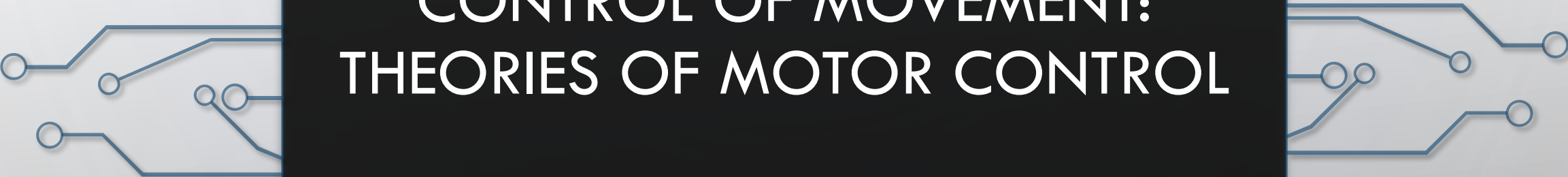
- Specify aspects of the environment that shape the movement itself
- Task-specific movements must conform to regulatory features of the environment to achieve the goal of the task
- Examples:
 - size, shape and weight of a cup to be picked up
 - type of surface we walk on



NON REGULATORY FEATURES

- May affect performance
- Movement does not have to conform to these features
- Examples:
 - background noise
 - presence of distractions



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CONTROL OF MOVEMENT: THEORIES OF MOTOR CONTROL

- Theories of motor control describe: viewpoints regarding how movement is controlled
- A theory of motor control is: a group of abstract ideas about the control of movement
- **A theory = a set of interconnected statements that describe unobservable structures or processes & relate them to each other & other observable events**
- Motor control theories often stress different aspects of the organization of the underlying neurophysiology & neuroanatomy of that action
- There is no one theory of motor control that everyone accepts



Science is built up of facts,
as a house is built of stones;
but an accumulation of facts
is no more a science than a
heap of stones is a house.

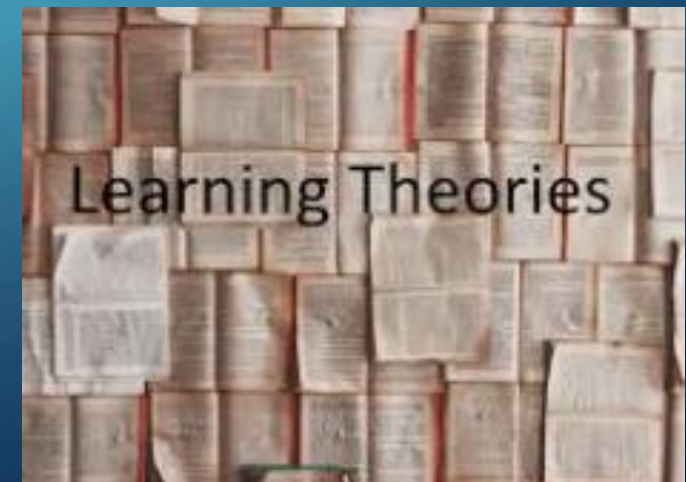
Henri Poincaré

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A THEORY GIVES MEANING
TO FACTS AS A BLUEPRINT
PROVIDES THE STRUCTURE
THAT TRANSFORMS
STONES INTO A HOUSE
(Miller, 2002)

VALUE OF THEORY TO PRACTICE:

- Rehabilitation practices reflect the theories / basic ideas we have about the cause and nature of function & dysfunction
- Actions of therapists are based on assumptions derived from theories
- Motor control theory is part of the theoretical basis for clinical practice
- All theoretical models are unified by the desire to understand the nature and control of movement. The difference is the approach
- Theories provide:
 - A framework for interpreting behaviour
 - A guide for clinical action
 - New ideas
 - Working hypotheses for examination & intervention



VALUE OF THEORY TO PRACTICE: FRAMEWORK FOR INTERPRETING BEHAVIOR

- Theory can help therapists to interpret the behavior / actions of patients with whom they work
- Allows the therapist to go beyond the behavior of one patient & broaden the application to a much larger number of cases
- Can be more / less helpful depending on: ability to predict / explain behavior of an individual patient

When a theory and its associated assumptions do not provide an accurate interpretation of a patient's behavior, it loses its usefulness to the therapist

- Theories can thus limit a therapist's ability to observe & interpret movement problems in patients

VALUE OF THEORY TO PRACTICE: GUIDE FOR CLINICAL ACTION

- Theories provide therapists with a possible guide for action
- Clinical interventions designed to improve motor control in the patient with neurological dysfunction are based on an understanding of:
 - the nature and cause of normal movement &
 - the basis for abnormal movement

Therapeutic strategies aimed at retraining motor control reflect this basic understanding



VALUE OF THEORY TO PRACTICE: NEW IDEAS: DYNAMIC & EVOLVING

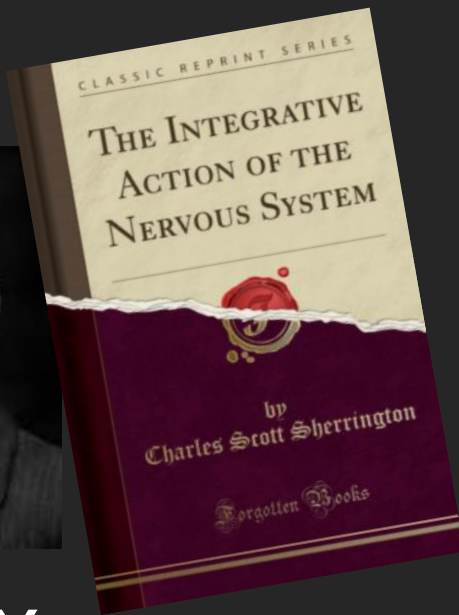
- Theories are dynamic – changing to reflect greater knowledge relating to the theory
- Changing & expanding theories shouldn't be a source of frustration to clinicians
- Expanding theories can broaden & enrich the possibilities for clinical practice
- New ideas related to examination & intervention will evolve to reflect new ideas about the nature & cause of movement



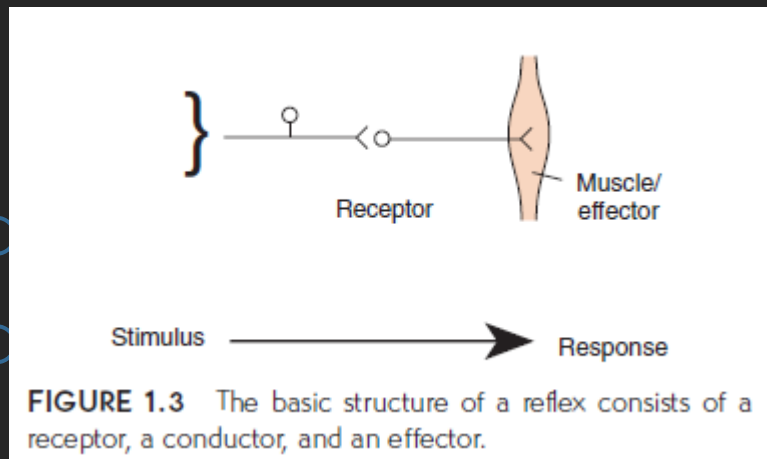
VALUE OF THEORY TO PRACTICE: WORKING HYPOTHESES FOR EXAMINATION & INTERVENTION

- Theories are not directly testable – it is abstract
- Theories generate hypotheses which are testable
- Information gained through hypotheses testing is used to validate or invalidate a theory
- Hypothesis-driven clinical practice transforms the therapist into an active problem solver

Using this approach to retrain the patient with motor dyscontrol calls for the therapist to generate multiple hypotheses (explanations) of why patients move (or do not move) in ways to achieve functional independence. Therapists will test many hypotheses, discard some and generate new explanations more consistent with the results



REFLEX THEORY:



- Sir Charles Sherrington, neurophysiologist (1800-1900)
- His research formed the experimental foundation for a classic reflex theory of motor control
- Basic structure of a reflex (Fig 1,3 p8)
- According to Sherrington:
- Reflexes = building blocks of complex behavior
- Complex behavior could be explained through combined action of individual reflexes chained together
- This view was unchallenged by many for 50 years & continues to influence thinking about motor control today

REFLEX THEORY: LIMITATIONS

- Cannot be considered the basic unit of behavior if both spontaneous & voluntary movements are recognized as acceptable classes of behavior

REASON: the reflex must be activated by an outside agent

- Does not adequately explain & predict movement that occurs in the absence of a sensory stimulus
 - *recently shown that animals can move in a relatively coordinated fashion in the absence of sensory input*
- Does not explain fast movements – i.e. sequences of movements that occur too rapidly to allow for sensory feedback from the preceding movement to trigger the next

EXAMPLE: an experienced & proficient typist moves from 1 key to the next so rapidly there's no time for sensory information from one keystroke to activate the next



REFLEX THEORY: LIMITATIONS

- The concept that a chain of reflexes can create complex behaviors, fails to explain the fact that a single stimulus can result in varying responses depending on context and descending commands

EXAMPLE: There are times when we need to override reflexes to achieve a goal

Normally touching something hot results in the reflexive withdrawal of the hand

HOWEVER – if a loved one is in a fire, we may override the reflexive withdrawal in order to pull that person away from the fire

- Reflex chaining does not explain the ability to produce novel movements
 - Novel movements put together unique combinations of stimuli and responses according to rules previously learned
 - *EXAMPLE: a violinist who has learned a piece on the violin and also knows the technique of playing the cello, can also play that piece on the cello without necessarily having practiced it on the cello*
 - *She has learned the rules for playing that piece and applied it to a novel situation*



CLINICAL IMPLICATIONS

- If chained or compounded reflexes are the basis for functional movement, clinical strategies designed to test reflexes should allow therapists to predict function
- A patient's movement behaviors would be interpreted in terms of the presence or absence of controlling reflexes
- Retraining motor control for functional skills would focus on enhancing or reducing the effect of various reflexes during motor tasks



HIERARCHICAL THEORY



- Researchers: nervous systems organized as hierarchy
- Hughlings Jackson (physician): brain has higher, middle & lower levels of control equated with higher association areas, the motor cortex and spinal levels of motor function
- Hierarchical control = organizational control that is top down, i.e. each successively higher level exerts control over the level below it (Fig 1.4 p9)
- In a strict vertical hierarchy:
 - lines of control never cross and
 - there's no bottom-up control

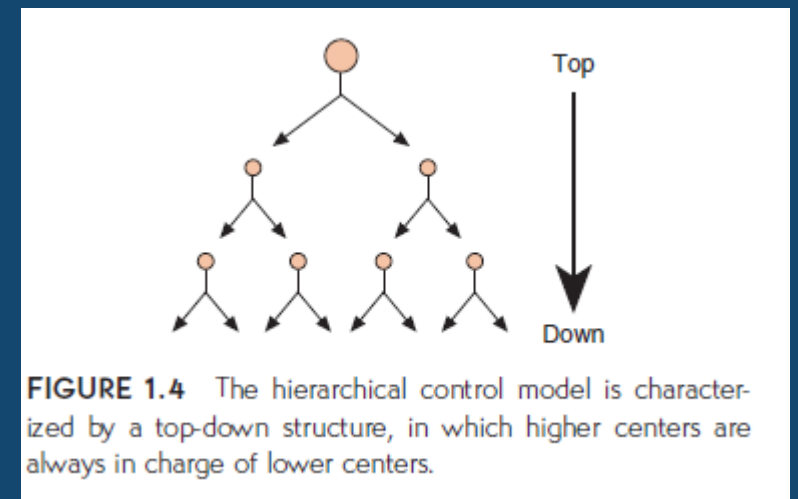
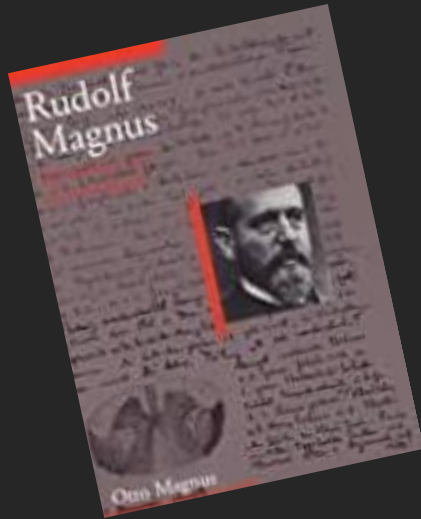


FIGURE 1.4 The hierarchical control model is characterized by a top-down structure, in which higher centers are always in charge of lower centers.



HIERARCHICAL THEORY



- Rudolf Magnus (1920's): explore function of different reflexes in different parts of the nervous system
- Found: reflexes controlled by lower levels of neural hierarchy are present only when cortical centers are damaged
- Imply that reflexes are part of a hierarchy of motor control in which higher centers normally inhibit these lower reflex centers



HIERARCHICAL THEORY



- Georg Schaltenbrand (1928): used Magnus's concepts to explain development of mobility in children & adults
- Described the movement of human mobility in terms of the appearance and disappearance of a progression of hierarchically organized reflexes
- **Pathology of the brain may result in persistence of primitive lower-level reflexes**
- Complete understanding of all the reflexes would allow determination of the neural age of a child or patient with motor control dysfunction

[illegible]

- Stephan Weisz (1938): thought hierarchically organized reflex actions were the basis for equilibrium in humans
- Described the ontogeny of equilibrium reflexes in the normally developing child & proposed a relationship between the maturation of these reflexes and the child's capacity to sit, stand & walk
- Results of all these experiments drawn together & referred to as: reflex / hierarchical theory of motor control
- Theory suggests that: motor control emerges from reflexes that are nested within hierarchically organized levels of the CNS

FIGURE 1.5 The neuromaturational theory of motor control attributes motor development to the maturation of neural processes, including the progressive appearance and disappearance of reflexes.

HIERARCHICAL THEORY

Neuroanatomical structures	Postural reflex development	Motor development
Cortex	Equilibrium reactions	Bipedal function
Midbrain	Righting reactions	Quadrupedal function
Brainstem spinal cord	Primitive reflex	Apedal function

- Arnold Gessel & Myrtle McGraw (1940's): detailed descriptions of maturation of infants
 - Applied current scientific thinking about reflex hierarchies of motor control to explain behaviors seen in infants
 - Normal motor development was attributed to increasing corticalization of the CNS
RESULTING IN: emergences of higher levels of control over lower-level reflexes
- = NEUROMATURATIONAL THEORY OF DEVELOPMENT
- This theory assumes that CNS maturation is the primary agent for change in development & minimize importance of other factors such as musculoskeletal development

CURRENT CONCEPTS RELATED TO HIERARCHICAL CONTROL

- New concept has evolved
- Neuroscientists confirmed importance of elements of hierarchical organization in motor control
- **Concept of strict hierarchy in which higher centers are always in control has been modified**
- Current concepts recognize the fact that each level of the nervous system can act on other levels (higher & lower), depending on the task
- Role of reflexes in movement modified: reflexes are not considered the sole determinant of motor control but only as one of many processes important to the generation & control of movement

LIMITATIONS

- Can't explain the dominance of reflex behavior in certain situations in normal adults
EXAMPLE: Stepping on a pin – immediate withdrawal of the leg

This is a reflex in the lowest level of the hierarchy dominating motor function

Bottom-up control

Thus not all low-level behaviors are primitive, immature and nonadaptive with all higher-level (cortical) behavior mature, adaptive and appropriate



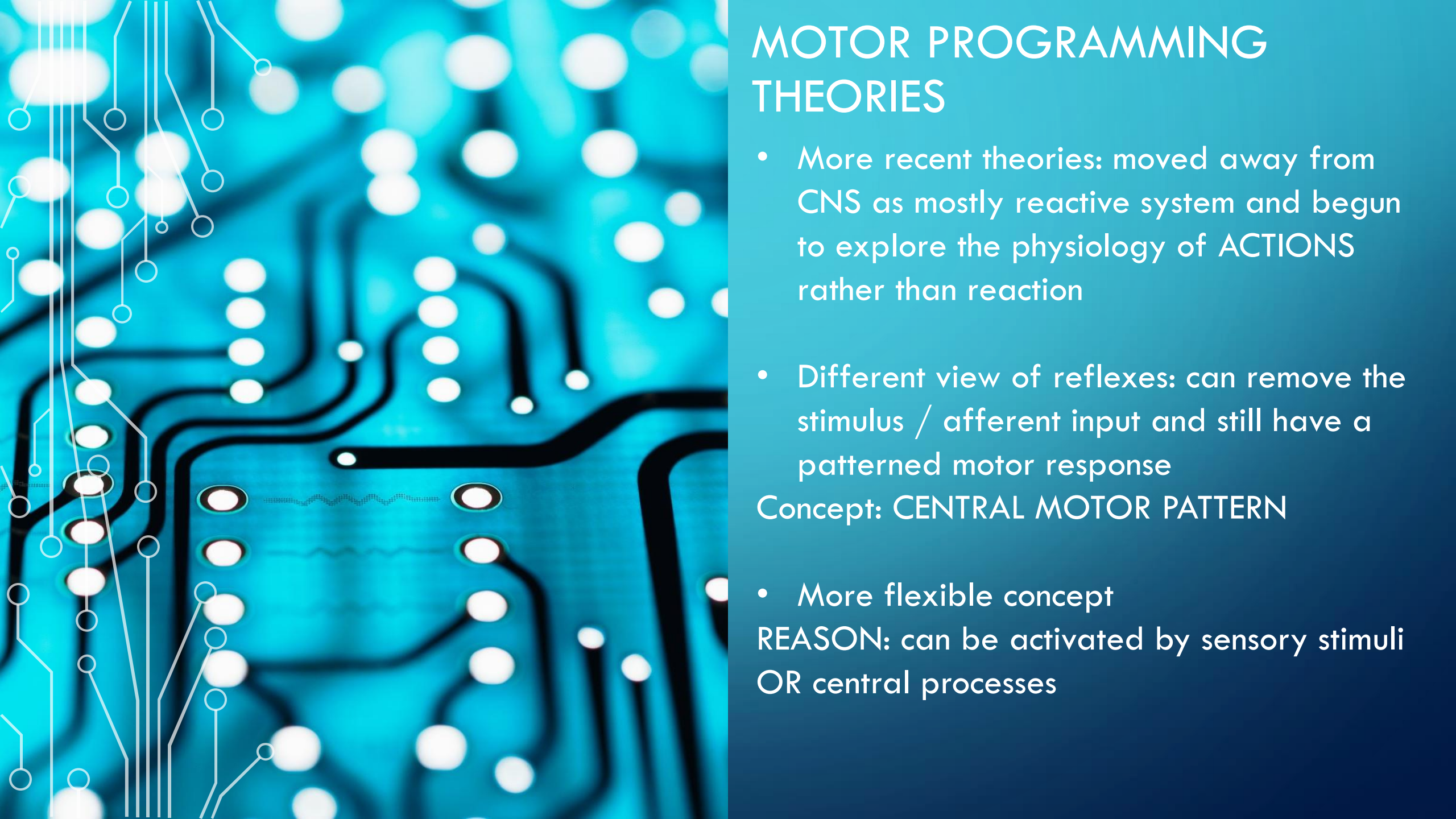
CLINICAL IMPLICATIONS

- Clinicians use the concept of abnormalities of reflex organization to explain disordered motor control in patients with neurologic disorders
- Signe Brunnstorm, physical therapist who pioneered early stroke rehabilitation used reflex hierarchical theory to describe disordered movement following a motor cortex lesion

“When the influence of higher centers is temporarily or permanently interfered with, normal reflexes become exaggerated and so-called pathological reflexes appear”

Berta Bobath, physical therapist, abnormal postural reflex activity in children with CP

“the release of motor responses integrated at lower levels from restraining influences of higher centers, especially that of the cortex, leads to abnormal postural reflex activity”



MOTOR PROGRAMMING THEORIES

- More recent theories: moved away from CNS as mostly reactive system and begun to explore the physiology of ACTIONS rather than reaction
- Different view of reflexes: can remove the stimulus / afferent input and still have a patterned motor response

Concept: CENTRAL MOTOR PATTERN

- More flexible concept
REASON: can be activated by sensory stimuli
OR central processes

- 
- Motor program theory of motor control has considerable experimental support
 - Movement is possible in the absence of reflexive action
 - Sensory input is not essential in driving movement BUT has an important function in modulating action
 - Reflexes do not drive action
 - Central pattern generators (CPGs) (spinally mediated motor programs) by themselves can generate such complex movements as walking
 - Important modulatory effects of incoming sensory inputs on the CPG
 - These experiments led to the motor program theory of motor control

- 
- The term motor program may be used to:

- 1) **identify a CPG:** a specific neural circuit like that for generating walking in the cat

- in this case the term represents: neural connections that are stereotyped and hardwired

- 2) **describe the higher-level motor programs that represent actions in more abstract terms**

- Existence of hierarchically organized motor programs that store the rules for generating movements so that we can perform these tasks with a variety of effector systems

Fig 1.6 p15 – hypothesized that the rules for writing a given word are stored as an abstract motor program at higher levels within the CNS

RESULT: Neural commands from these higher centers used to write your name could be sent to various parts of the body. Elements of written signature remain constant regardless of the part of the body used to perform the task

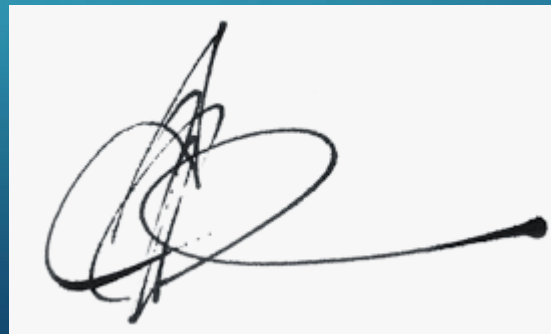
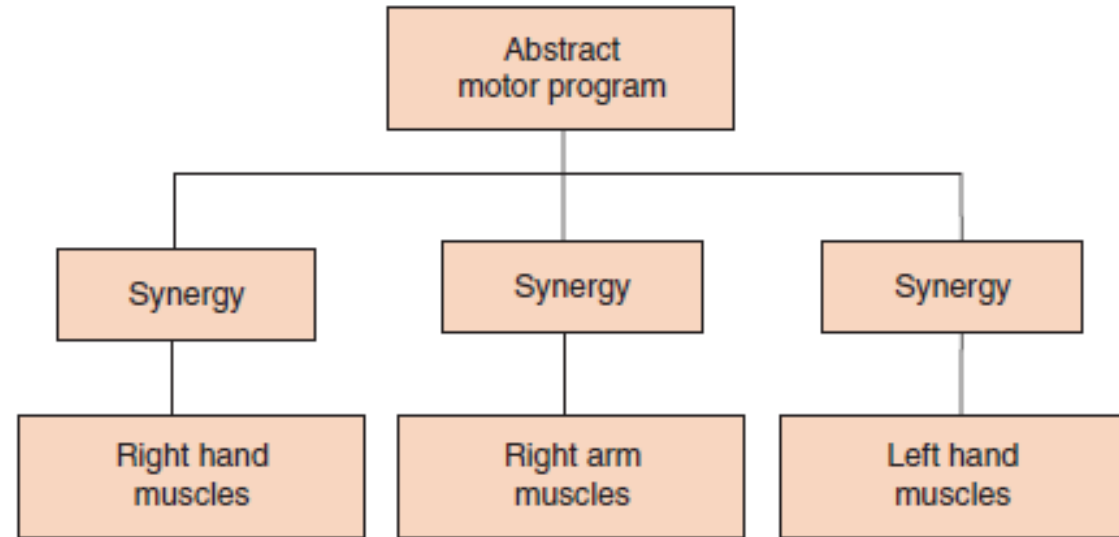


FIGURE 1.6 Levels of control for motor programs and their output systems. Rules for action are represented at the highest level, in abstract motor programs. Lower levels of the hierarchy contain specific information, including muscle response synergies, essential for effecting action.



LAB ACTIVITY 1-2

Objective: To apply to concept of motor program to functional movement.

Procedure: Write your signature as you normally would on a small piece of paper. Now write it larger, on a blackboard. Now try it with your other hand.

Assignment

1. Examine the three signatures carefully, looking for common elements found in all of them.

2. Write down the common elements you found. What do you think are the causes for both the common elements and the differences? How do your results support or contradict the theory of motor programs?

LIMITATIONS

- Concept of CPGs was never intended to replace the concept of the importance of sensory input in controlling movement
- It only expanded our understanding of the flexibility of the nervous system in creating movements to include its ability to create movements in isolation from feedback

- A central motor program can't be considered the sole determinant of action

EXAMPLE: 2 identical commands to the elbow flexors will produce different movements depending on whether your arm is resting at your side or you are holding your arm out in front of you

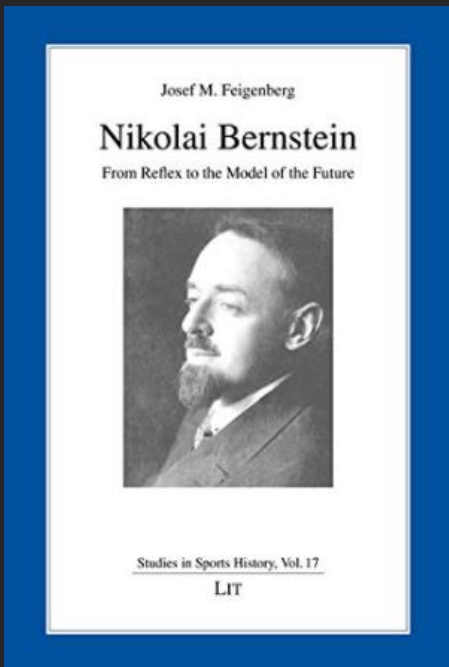
The forces of gravity will act differently on the limb in the 2 conditions – modifying the movement

Fatigued muscles: similar nervous system demands will yield different results

- Motor control program does not take into account that the nervous system must deal with musculoskeletal & environmental variables in achieving movement control

CLINICAL IMPLICATIONS

- Allowed clinicians to move beyond a reflex explanation for disordered motor control
- Explanation of abnormal movement have been expanded to include problems resulting from abnormalities in CPGs or higher-level motor programs
- In patients whose higher levels of motor programming are affected – the motor program theory suggests the importance of helping patients relearn the correct rules for action
- Intervention should focus on retraining movements important to a functional task and not just reeducating specific muscles in isolation



SYSTEMS THEORY:

Dynamical Systems Theory

**Complex with many
important points**

- Nicolai Bernstein (1896-1966): can't understand the neural control of movement without an understanding of the characteristics of the system you are moving & the external and internal forces acting on the body
- Looked at the whole body as a mechanical system, with mass & subject to external (gravity) and internal (inertial and movement-dependent) forces
- The same central command could result in quite different movements: interplay between external forces & variations in the internal conditions
- **Different commands could result in same movement**
- Control of integrated movement, distributed throughout many interacting systems working cooperatively to achieve movement: distributed model of motor control



SYSTEMS THEORY:

- We have many degrees of freedom that need to be controlled

EXAMPLE: we have many joints. all of which flex or extend and many could be rotated as well, complicating movement control

“Coordination of movement is the process of mastering the redundant degrees of freedom of the moving organism”

- Converting the body into a controllable system
 - Hypothesized that hierarchical control exists to simplify the control of the body's multiple degrees of freedom
- Movement repertoire like sentences made of many words
Letters in words: muscles
Words: Synergies – important to solve degrees of freedom
Sentences: Actions



SYSTEMS THEORY:



- Higher levels of nervous system activate lower levels
- Lower levels activate synergies or groups of muscles that are constrained to work together as a unit
- When the demands of a task increase the control signal to the synergy increases – leading to parallel increases in the activation in all muscles in the synergy
- Constraining muscles to work together as a unit
- Few synergies make up almost whole variety of know movements. Some simple synergies include:
 - locomotor
 - postural
 - respiratory

Synergy

Synergy is an interaction or cooperation giving rise to a whole that is greater than the simple sum of its parts. The term synergy comes from the Attic Greek word συνεργία synergia from synergos,



SYSTEMS THEORY:

- **Principle of abundance = synergies are used to ensure flexible and stable performance of motor tasks**
- Synergy = A neural organization of a multielement system (e.g. muscles) that:
 - 1) organizes sharing of a task among a set of elemental variables such as the muscles
 - 2) ensure covariation among elemental variables with the purpose of stabilizing performance variables (center of mass in posture control or the end point in a reaching task)
- Synergies show:
 - stability against perturbations &
 - flexibility to solve concurrent tasks
- A muscle can belong to multiple synergies



SYSTEMS THEORY:

- An individual muscle has a unique contribution to each synergy
- Total activation of a muscle is dependent on:
 - the simultaneous activation of multiple synergies containing that muscle &
 - the relative contribution of that muscle in each of these synergies
- Dynamic systems theory: expansion on the systems theory by Bernstein
- In principle the theories are very similar at their foundation

SYSTEMS THEORY:



- **Self-organization commonly found in nature**
- **This principles state that:
when a system of individual parts comes together, its
elements behave collectively in an ordered way**
- No need for a “higher” center issuing instructions or commands in order to achieve coordinated action
- Applying this principle predicts that movement could emerge as a result of interacting elements without the need for specific commands or motor programs within the nervous system
- Critical feature of dynamic systems = nonlinear properties

SYSTEMS THEORY:

- **Nonlinear system = one whose output is not proportional to its input**
- A behavior that transforms into a new configuration when a single parameter of that behavior is gradually altered & reaches a critical value

EXAMPLE: as an animal walks faster and faster there's a point at which, suddenly it shifts into a trot and as the animal continues to move faster, there's a second point at which it shifts to a gallop

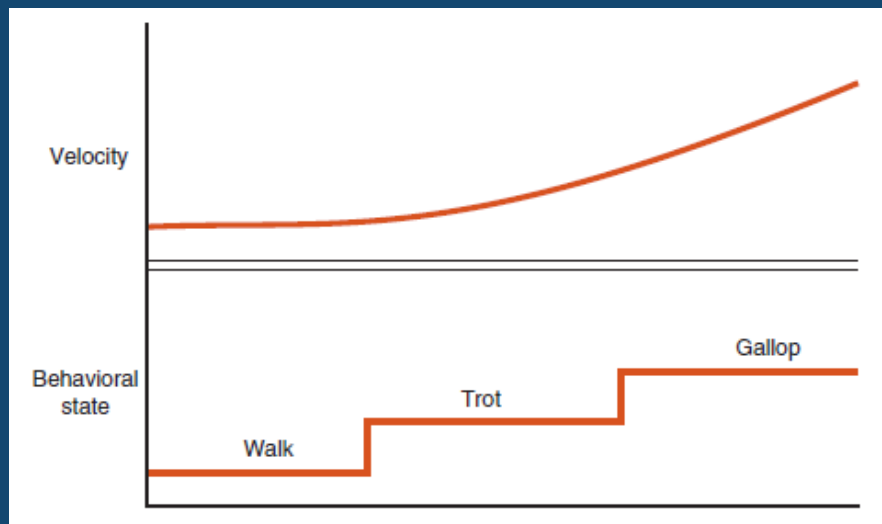
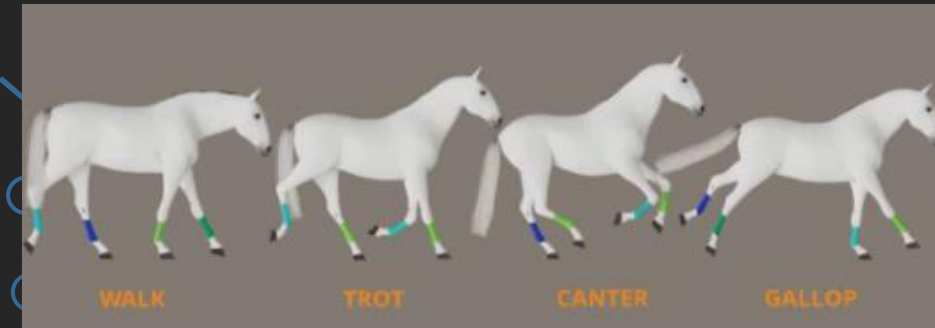


FIGURE 1.7 A systems model predicts discrete changes in behavior resulting from changes in the linear dynamics of a moving system. For example, as locomotion velocity increases linearly, a threshold is reached that results in a nonlinear change in the behavioral state of the moving animal from a walk to a trot to a gallop.

SYSTEMS THEORY:



- What causes this change from one behavioral pattern to a new pattern?
 - the new movement emerges because of a critical change in one of the systems called a “control parameter”
- **Control Parameter = a variable that regulates change in the behavior of the entire system**
- In the example the control parameter = **velocity**
- Dynamic action perspective has de-emphasized the notion of commands from the CNS in controlling movement & sought physical explanations that may contribute to movement characteristics as well
- Human movement has inherent variability that is critical to optimal function



SYSTEMS THEORY:

- Movement variability includes variations that occur normally in motor performance across multiple repetitions of a task
- In motor program theory:
variability is considered to be the consequence of errors in motor performance, with the assumption that as performance improves during skill acquisition, error and consequently variability decreases
- In dynamic systems theory
variability not considered the result of error but rather as a necessary condition of optimal function

Optimal variability provides for flexible, adaptive strategies, allowing adjustment to environmental change and as such is a central feature of normal movement



SYSTEMS THEORY:

- Too little variability – can lead to injury e.g. repetitive strain problems
- Too much variability – leads to impaired movement performance e.g. those occurring in persons with ataxia
- **Small amount of variability indicates a highly stable behavior often viewed as an attractor state**
- **Attractor states = highly stable , preferred patterns of movement, many of which are used to accomplish common ADLs**
- EXAMPLE: animals all habitually walk at a preferred pace representing an attractor state for walking speed specific to the individual.
- Walking at other speeds is possible BUT barring outside influences, individuals tend to walk at a preferred pace which is energetically most efficient

SYSTEMS THEORY:

- **Attractor well = the degree to which flexibility exists to change a preferred pattern of movement**
- Fig 1.8 p13

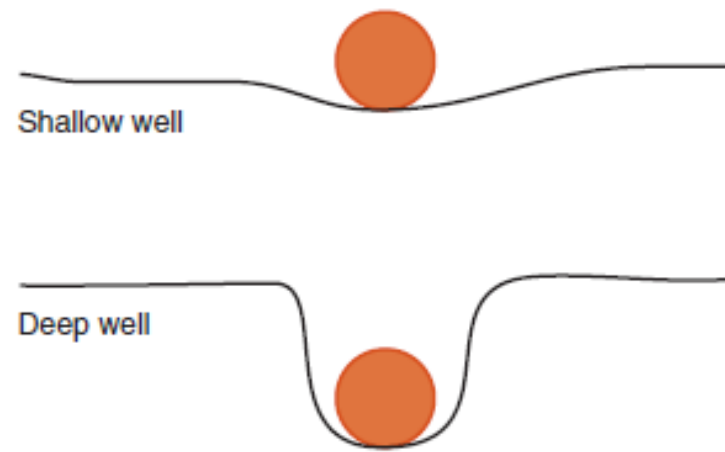


FIGURE 1.8 Attractor wells describe the variability in a preferred pattern of movement.

- Deeper well – harder to change preferred pattern, suggesting a stable movement pattern



SYSTEMS THEORY:

- Movement patterns in patients could be characterized as stable or unstable, based on difficulty associated with changing them
 - easier to change an unstable movement pattern with a shallow attractor well VS
 - a stable movement pattern with a deep attractor well
- **Stable movement patterns become more unstable or variable just prior to transition to a new movement pattern**

EXAMPLE: if persons are asked to move their 2 index fingers of the right & left hand out of phase (one is flexing & one extending) while increasing speed of movements, an abrupt phase transition occurs between the 2 fingers. Asymmetrical out-of-phase mode shifts suddenly to a symmetrical in-phase mode (both fingers flexing) involving a shift to activation of homologous muscle groups.

TABLE 1.3 P14: CRITICAL CONCEPTS ASSOCIATED WITH THE SYSTEMS THEORY OF MOTOR CONTROL

Concept	Definition
Degrees of freedom	The body is a mechanical system with many degrees of freedom. Systems theory stresses the importance of the above Coordination of movement is the process of mastering the redundant degrees of freedom of the moving organism
Synergies	Synergies proposed as a solution to the degrees of freedom problem Concept of synergies modified to reflect the flexible, adaptive nature of synergies rather than fixed stereotypical patterns of activity
Self-organization	Principles of self-organization found in nature, applied to motor control Solves the degrees of freedom Organization emerges from interaction of elements and does not require central commands

TABLE 1.3 P14: CRITICAL CONCEPTS ASSOCIATED WITH THE SYSTEMS THEORY OF MOTOR CONTROL

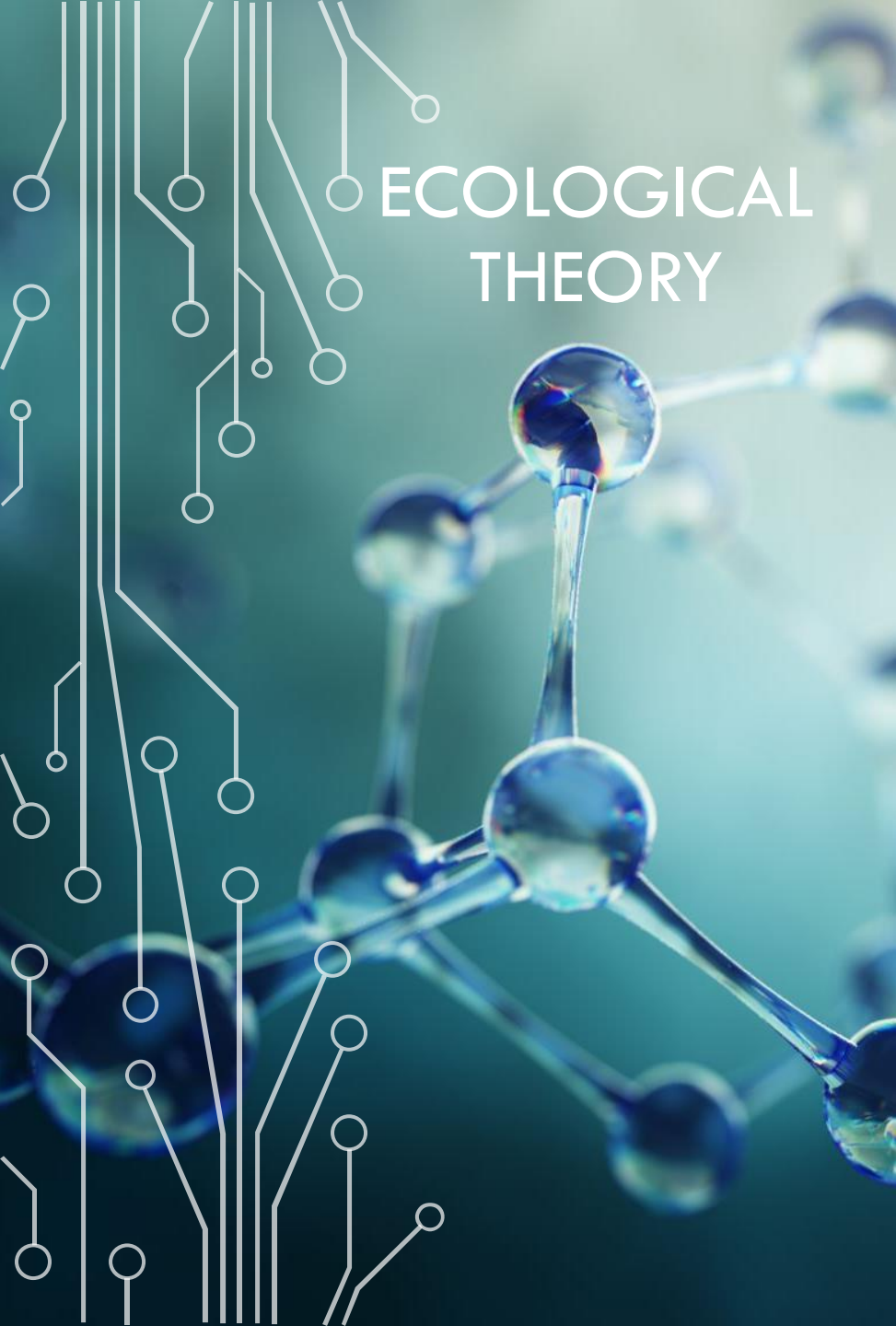
Concept	Definition
Nonlinear behavior	Self-organization systems often have nonlinear properties Nonlinear behavior is one that transforms into a new configuration when a single parameter of that behavior is gradually altered & reaches a critical value E.g. Walk, trot and gallop emerging from a change in velocity
Variability	Systems theory believes that variability of movement is not due to error Variability is rather a necessary condition for optimal function The concept of attractor wells is used to characterize the variability & flexibility of a movement pattern The deeper the well, the less variable and flexible the movement A shallow well suggests an unstable pattern There's a significant increase in variability of a movement just prior to a change to a new movement pattern (a shift to a new attractor well) E.g. walking patterns become more variable just prior to a shift from walk to trot

CLINICAL IMPLICATIONS

- It stresses the importance of understanding the body as a mechanical system
- Movement is not determined solely by the output of the nervous system BUT is the output of the nervous system as filtered through a mechanical system: the body
- When working with a patient with CNS deficit the therapist should examine the contribution of impairments in the musculoskeletal system & nervous system to overall loss of motor control
- The examination & intervention should not only focus on impairments in individual systems contributing to motor control but also on the effect of interacting impairments among multiple systems
- Movement is an emergent property – it emerges from the interaction of multiple elements that self-organize based on certain dynamic properties of the elements

CLINICAL IMPLICATIONS

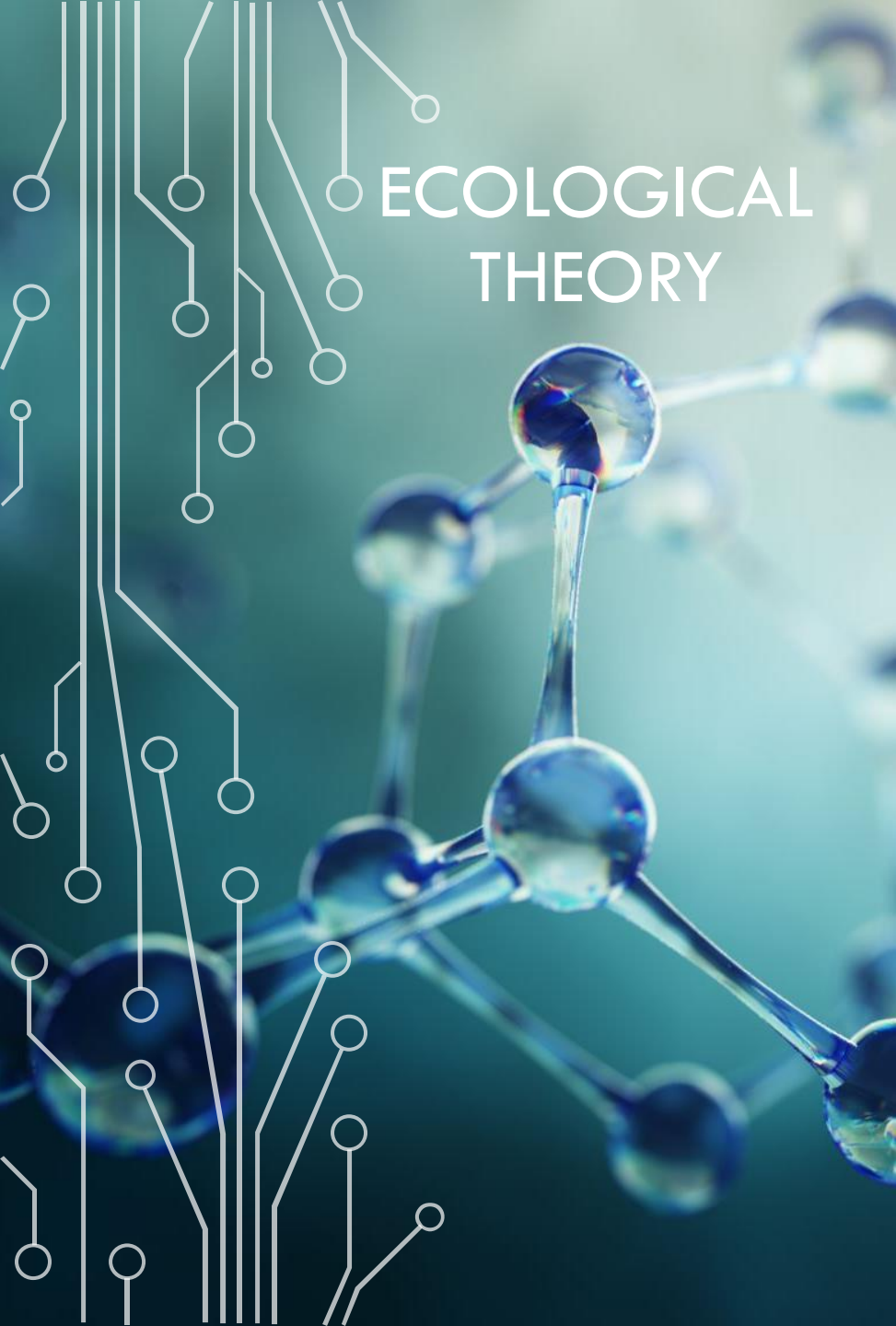
- Shifts or alterations in movement behavior can often be explained in terms of physical principles rather than neural structures
- Understanding more about physical or dynamic properties of the human body enables clinicians to use these properties when helping patients regain motor control
 - E.g. VELOCITY – important contributor to dynamics of movement
Patients are often asked to move slowly in an effort to move safely
YET: this approach to retraining doesn't take into account the interaction between speed and physical properties of the body which produce momentum – therefore it can help a weak patient move with greater ease
 - Variability viewed as critical element of normal function – therapists will encourage patients to explore variable & flexible movement patterns that will lead to success in achieving performance goals vs variability as error, trying to reduce error



ECOLOGICAL THEORY

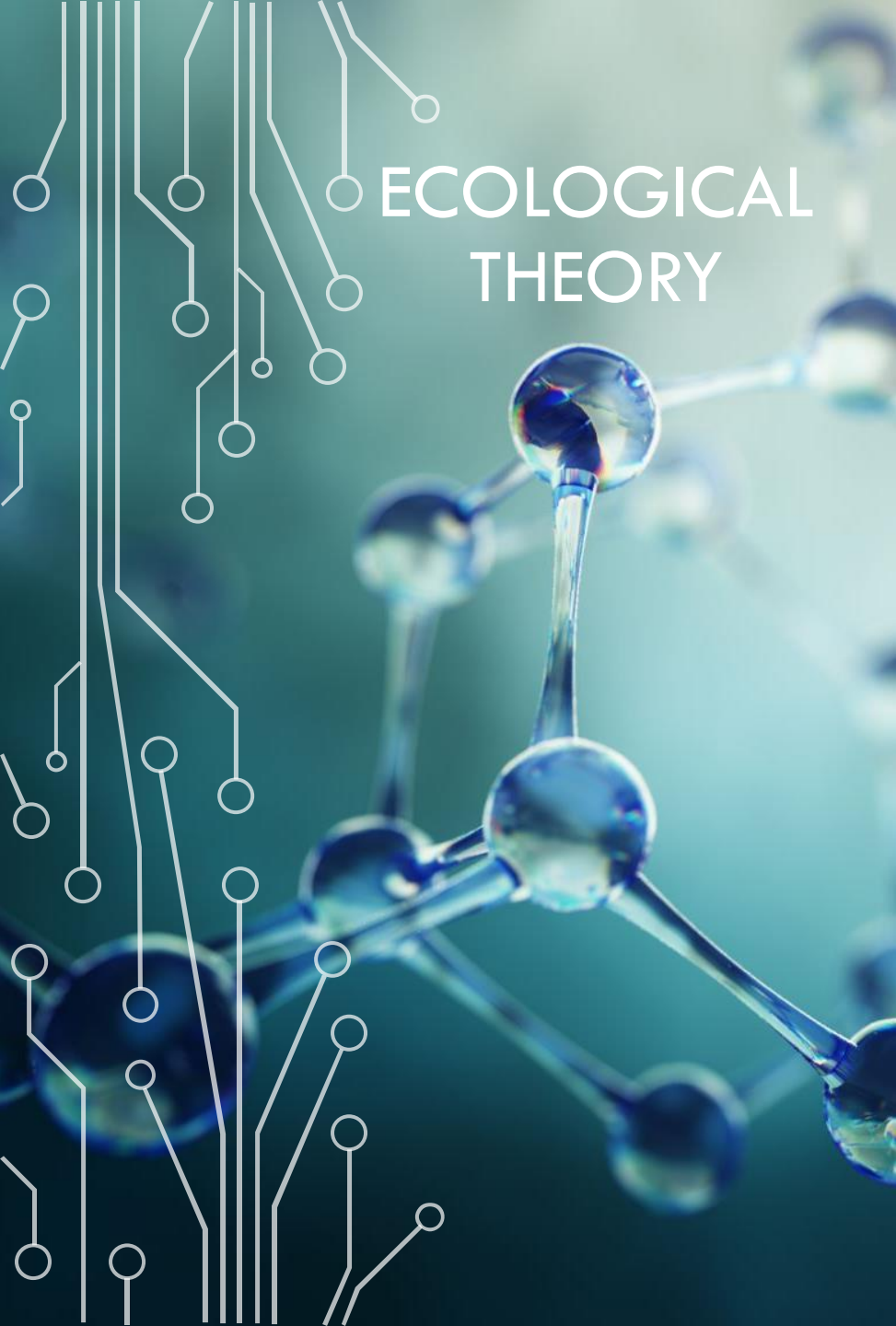
- James Gibson (1960's): explored the way in which our motor systems allows us to interact most effectively with the environment in order to perform goal-oriented behavior
- **How information, relevant to our actions is detected in the environment & how it's used to control movement**
- **Ability to use perceptions to guide action emerges early in life**

EXAMPLE: at 15 weeks an infant doesn't automatically reach for every object that passes by, **INSTEAD** they use perceptions related to velocity to determine in advance whether they will be able to reach it or not



ECOLOGICAL THEORY

- Ecological approach to motor control suggests that motor control evolved so that animals could cope with the environment around them
Moving in it effectively to find food, run away from predators, build shelter and even play
- **Novel to this approach: 1st time researchers began to focus on how actions are geared to the environment**
- **Actions require perceptual information that is specific to a desired goal-directed action performed in a specific environment**
- Organization of action is specific to the task & environment in which the task is being performed
- Not sensation that's important but perception



ECOLOGICAL THEORY

- What is needed? The perception of environmental factors important to the task
- Perception focuses on detecting information in the environment that will support the actions necessary to achieve the goal
- Important to determine how an organism detects information in the environment that is relevant to action, what form this information takes and how this information is used to modify and control movement
- This theory broadened the understanding of nervous system function from that of a sensory / motor system, reacting to environmental variables to that of a perception / action system that actively explores the environment to satisfy its own goals

LIMITATIONS

- Give less emphasis to the organization & function of the nervous system that led to this interaction of the organism & its environment
- Research emphasis shifted from the nervous system to the organism / environment



CLINICAL IMPLICATIONS

- Major contribution of this view: Describe the individual as an active explorer of the environment
- Above allows the individual to develop multiple ways to accomplish a task
- Adaptability is important in the way we organize movement to accomplish a task as well as the way we use perception
- Important part of intervention: helping the individual explore the possibilities for achieving the goal of a functional task in multiple ways, given the constraints of different environments – since features in the environment impact the selection & execution of goal-directed movements
- Effective motor control requires the patient to learn to perceive the critical aspects of an environment (affordances) that impact how movement is organized
- Critical aspect of rehabilitation process is controlling & manipulating the environment so that patients can learn to perceive critical features & adapt movement accordingly

WHICH THEORY OF MOTOR CONTROL IS BEST?

- **There is no single theory that has it all**
- **Best theory of motor control – one that combines elements from all theories presented**
- **Comprehensive / Integrated theory:**
 - **Recognizes the elements of motor control we know about**
 - **Leaves room for things we do not know**
- **Currently the theory of motor control used in this module: systems theory**

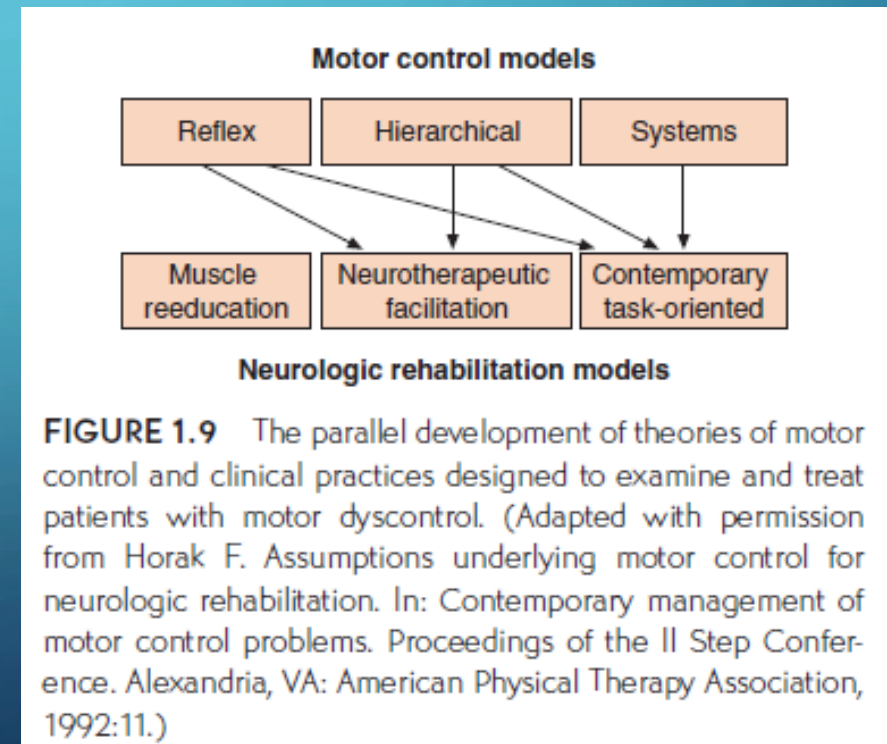
HOWEVER: differs from Bernstein's systems theory and has evolved to incorporate many other concepts proposed by other theories of motor control.

 - **This approach argues that it's critical to recognize that movement emerges from interaction between the individual, the task and the environment in which the task is being carried out**
 - **Movement is not solely the result of muscle-specific motor programs or stereotyped reflexes but results from a dynamic interplay between perception , cognition and action systems**

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PARALLEL DEVELOPMENT OF CLINICAL PRACTICE & SCIENTIFIC THEORY

- **There is parallel developments between scientific theory & clinical practice**
- Neuroscience researchers – identify the scientific basis for movement & movement disorders
- Clinician – develop the applications of this research
- Scientific assumptions about the important elements that control movement are changing and so is clinical practice related to treatment of the patient with a neurological deficit
- **Clinical practice evolves in parallel with scientific theory - as clinicians assimilate changes in scientific theory and apply them to practice**





NEUROLOGIC REHABILITATION: REFLEX-BASED NEURO-FACILITATION APPROACHES

- Neuro-facilitation still dominate the way clinicians treat the patient with a neurological deficit
- Approaches include:
 - Bobath approach
 - Rood approach
 - Burnnstorm's approach
 - Proprioceptive neuromuscular fascilitation (PNF)
 - Sensory integration therapy
- Approaches based largely on assumptions drawn from both the reflex & hierarchical theories of motor control

- 
- Prior to development of neuro-facilitation approaches, therapy for patients with neurological dysfunction was directed largely at: changing function at the level of the muscle itself – muscle re-education approach to intervention
 - Muscle re-education approach was effective in managing movement disorders resulting from polio BUT less impact on altering movement patterns in patients with upper motor neuron lesions
 - Clinicians working with patients with upper motor neuron (motor cortex and pyramidal tract) lesions began to direct clinical efforts toward modifying the CNS itself
 - Neuro-facilitation approaches focused on retraining motor control through techniques designed to facilitate and/or inhibit different movement patterns

- **Facilitation:**

Intervention techniques that increase the patient's ability to move in ways judged to be appropriate by the clinician



- **Inhibitory techniques:**

Decrease the patient's use of movement patterns considered to be abnormal



UNDERLYING ASSUMPTIONS

- Neuro-facilitation approaches are largely associated with the reflex & hierarchical theories of motor control
- Clinical practices have been developed based on assumptions regarding the nature & cause of normal motor control, abnormal motor control & the recovery of function
- Thus approach suggest: Normal movement results from a chain of reflexes organized hierarchically within the CNS *THUS* control is top down
- Normal movement requires that the highest level of the CNS (the cortex) be in control of the intermediate (brainstem) & lower (spinal cord) levels of the CNS
- Process of normal development (corticalization) is characterized by the emergence of behaviors organized at sequentially higher & higher levels in the CNS

UNDERLYING ASSUMPTIONS

- Great emphasis on: understanding that incoming sensory information stimulates & thus drives a normal movement pattern
- Explanations regarding physiological basis for abnormal motor control from a reflex and hierarchical perspective largely suggest that: a disruption of normal reflex mechanisms underlies abnormal movement control
- Assumed that lesions at the highest cortical levels of the CNS cause release of abnormal reflexes organized at lower levels within the CNS – constrains the patient's ability to move normally
- Another assumption is that abnormal / Atypical patterns of movement seen in patients with motor cortex lesions are the direct result of the lesion itself VS considering some behaviors as developing secondary to the lesion / in response to the lesion (compensatory to the lesion)

UNDERLYING ASSUMPTIONS

- Predicted that in the child with motor cortex lesions, the process of increasing corticalization is disrupted – result: motor control is dominated by primitive patterns of movement organized at lower levels of the CNS
- In the adult with acquired motor cortex lesions, damage to higher levels of the CNS probably results in a release of lower centers from higher-center control
- Primitive and pathologic behaviors organized at these levels reemerge to dominate, preventing normal patterns of movement from occurring
- Central assumption on recovery of function in the patient with a motor cortex lesion: recovery of normal motor control can't occur unless higher centers of CNS regain control over lower centers.

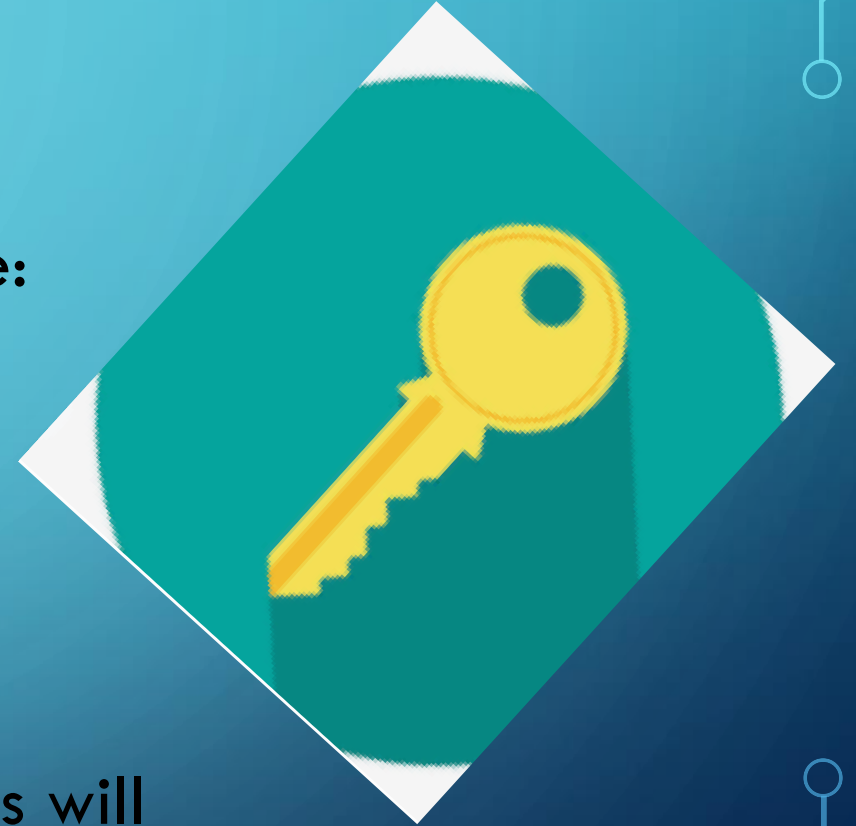
According to this approach recovery of function repeats development with higher centers gradually regaining dominance over lower centers of the CNS

UNDERLYING ASSUMPTIONS

- 2 Key Assumptions:

1) Functional skills will automatically return once:
abnormal movement patterns are inhibited &
normal movement patterns are facilitated

2) repetition of these normal movement patterns will
automatically transfer to functional tasks



CLINICAL IMPLICATIONS

- Examination of motor control should focus on identifying the presence / absence of normal & abnormal reflexes controlling movement
 - Intervention should be directed at modifying reflexes that control movement
 - Importance of sensory input for stimulating normal motor output suggests an intervention focus of modifying the CNS through sensory stimulation
 - Hierarchical theory suggests that one goal of therapy is to regain independent control of movement by higher centers of the CNS
- Intervention is geared toward helping the patient regain normal patterns of movement as a way of facilitating functional recovery
- Neuro-facilitation approach still dominates, but currently has greater emphasis on explicitly training function and less emphasis on inhibiting reflexes and retraining normal patterns of movement. Also more consideration of motor learning principles when developing interventions

Boundaries between approaches are less distinct

Each approach integrates new concepts related to motor control into its theoretical base



TASK-ORIENTED APPROACH:

- New approach to retraining
- Previously referred to as systems approach
- Also referred to by others as motor control or motor learning approach
- Whatever the name, these newer methods of clinical practice are based on concepts emerging from research in the fields of:
 - motor control
 - motor learning
 - rehabilitation science
- **Clinical practice = dynamic & changing in response to emerging evidence**
- Approach presented in textbook referred to as: task-oriented approach

UNDERLYING ASSUMPTIONS

- Assumed that normal movement emerges as an interaction among many different systems – each contributing different aspects of control
- Movement is organized around a behavioral goal & is constrained by the environment
- The role of sensation in normal movement is not limited to a stimulus / response reflex mode but is essential to predictive & adaptive control of movement
- Assumptions regarding abnormal motor control: movement problems result from impairments in one or more of the systems controlling movement
- Movements observed in the patient with a motor cortex lesion represent behavior that emerges from the best mix of the systems remaining to participate.

THUS what is observed is not just the result of the lesion itself but also of the efforts of the remaining systems to compensate for the loss & still be functional HOWEVER: Compensatory strategies not always optimal; Intervention Goal: improve efficiency of such strategies

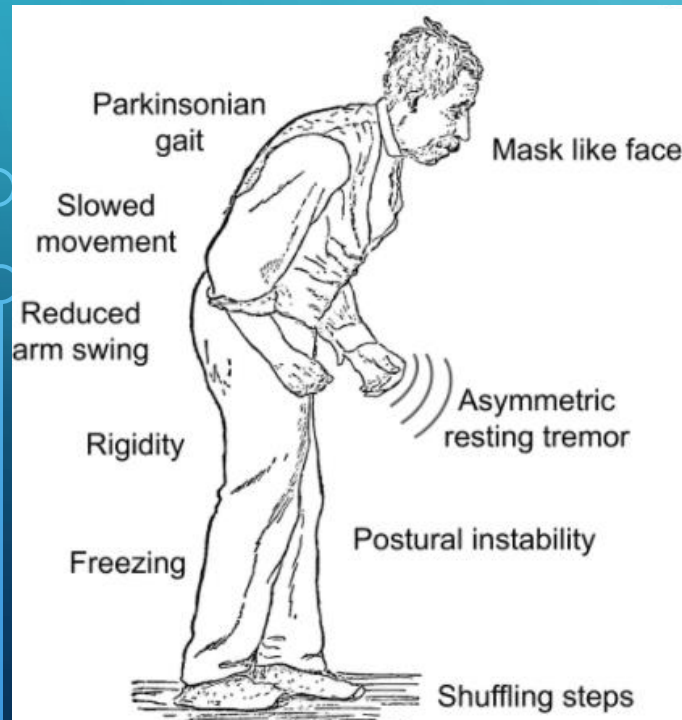
CLINICAL IMPLICATIONS

- When training movement control it's essential to work on identifiable functional tasks vs movement patterns for movement's sake alone
- A task-orientated approach to intervention assumes that patients learn by actively attempting to solve the problems inherent in a functional task RATHER than repetitively practicing normal patterns of movement, independent of a specific task goal
- Adaptation to changes in environmental context is a critical part of recovery of function
- Patients are helped to learn a variety of ways to solve the task goal rather than a single-muscle activation pattern

CASE STUDIES

- Familiarize yourselves with the case studies and conditions in Table 1.4 p 18-20 as we will often be referring back to these case studies for practical examples

John →



SPINOCEREBELLAR ATAXIAS

XpertDox
Clinical, Education, Research

Progressive, degenerative, genetic disease with multiple clinical types	Affects 150,000 people in the US	Risk factors include positive family history of degenerative brain disorders
Symptoms are poor coordination of hands, speech & eye movements	Diagnosed by genetic testing, spinal tap & MRI of brain & spine	No known effective treatment or cure
Supportive care, speech and physical therapy helps	Complications are severe disability & death	Patients with SCA types 1-3 & 7 reports severe disease & early onset

← Mike

Jean →

Hemiparesis

Hemiparesis occurs when one side of the body is weakened, and it typically impacts your limbs and facial muscles. It affects about 8 out of every 10 stroke survivors. Patients may experience limited movement in their arms, hands, legs, or facial muscles, which can lead to increased difficulty performing everyday activities.

Experiencing a one-sided weakness in your arms, hands, face, chest, legs, or feet can cause the following in patients:



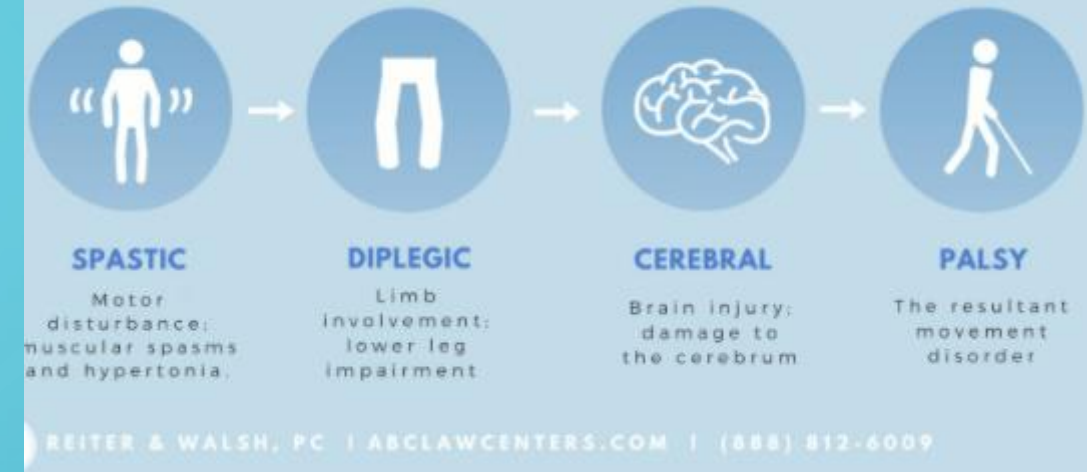
CASE STUDIES

Thomas →

← Sue

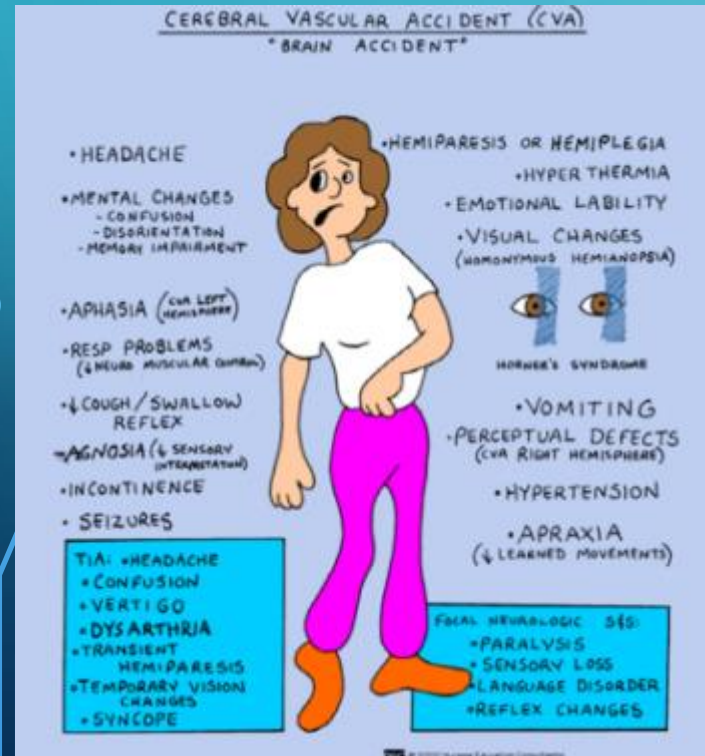
↓ Bonnie

WHAT IS SPASTIC DIPLEGIC CEREBRAL PALSY?



Malachi →

← Genise



CEREBRAL PALSY CLASSIFICATION:

Spastic	Ataxic	Athetoid	Mixed
It's the most common type of CP. Occurring Between 70-80%	Occurring between 5-10%	Occurring between 5-10%	It is the most difficult CP to treat as sometime it is unpredictable in its symptoms.
This type of cerebral palsy includes Muscles appear stiff and tight.	Have difficulty with visual and/or auditory processing.	Its mixed muscle tone- both hypertonia and hypotonia mixed with involuntary motions.	It's a mixed symptom of athetoid, ataxic and spastic CP.
Motor Cortex Damage	Cerebellum Damage		Motor Cortex Damage, Basal Ganglia Damage and Cerebellum Damage

What feels like the end
is often
the
beginning

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