Movement Education and Motor Learning – Where Ortho and Neuro Rehab Collide

Roderick Henderson, PT, ScD, OCS
Wendy Herbert, PT, PhD
Janna McGaugh, PT, ScD, COMT
Jill Seale, PT, PhD, NCS

Objectives

1. Identify and understand theories of motor control and motor learning
2. Review anatomy and physiology involved in motor control
3. Identify pathophysiology of motor control
4. Describe the role of learning in plasticity and recovery of function.
5. Examine the key components required for motor learning
6. Know the three elements of effective neuromuscular rehab programs in an orthopedic setting

Objectives Continued

7. Recognize cognitive-behavioral factors which may influence recovery of neuromuscular function.
8. Understand the neuromuscular changes occurring with traumatic and non-traumatic musculoskeletal problems.
9. Identify the factors that maximize learning and neuroplasticity in patients with neurological injury or disease.
10. Apply the concepts of motor learning and intensity of practice in treatment planning in patients with neurological injury or disease.
11. Integrate motor learning concepts into treatment planning with patient cases.
Questions we want to answer

• How can we best structure practice to ensure learning?
• How to ensure learning in one context transfers to others?
• Does simplifying task result in more efficient learning?
• What is best way to promote neuroplasticity and adaptation?
  — Shumway-Cook & Woolacott, 2012

Historical Perspective of Motor Control Theories

“No one theory is universal in explanation of movement control... select pieces which are evidence based and clinically relevant, apply in systematic fashion, and share with colleagues”
— Perry SB, 1998

Motor Control Theories

• Description of unobservable structures and processes and their relationship to observable events
• Model of how movement is achieved
• Assessment and treatment approaches are driven or biased by the theoretical model
• Basic question: Who’s in control
Reflex Theory

- Sherrington’s theory from late 1800s and early 1900s
- Complex movements explained by combined actions of individual reflexes – reflex chaining
- Movement is essentially the sum of reflexes
- Sensation is necessary

Hierarchical Theory

- Brain as the supercomputer idea
- Top down model
- Reflex/hierarchical theory
  - Motor control is result of reflexes nested within hierarchy of CNS- Shumway-Cook, Woollacott, 2012

Motor Programming Theories

- Central motor pattern or motor program
- Explains how movements occurs in absence of sensory feedback
- Higher level motor programs representing actions in abstract terms; store rules for generating movements
Systems Theory

- Considering whole system, not just neural components of movement
- Viewed whole body as mechanical system
- Control of integrated movement distributed throughout many interactive, cooperative systems
- Hypothesized a hierarchical control which utilizes synergies to control body’s multitude of degrees of freedom
  — Bernstein N, 1967

Dynamic Action Theory

- Also known as Dynamic Systems Theory
- Motor tasks are problems to be solved and solutions are movement strategies generated by system — Higgins S, 1991
- Based on the principle of self organization
- Individual parts, when put together, act collectively in ordered way
- No need for instructions from higher centers
- Movement emerges as result of interacting elements
  — Shumway-Cook, Woollacott, 2012

Prescriptions v. Constraints

Newell, 1991
Ecological Theory

- How motor systems interact with environment during goal directed behaviors
  - Gibson, 1966
- Use of perceptions to guide actions
- Motor control evolved so organisms could cope with environment
- First focus on how actions geared to environment
- Sensation not important... its perception

Motor Learning Defined

- Acquisition and/or modification of movement
- After injury, reacquisition of movement skills lost
- Processes associated with practice or experience leading to permanent changes in skill
  - Shumway-Cook, Woollacott, 2012

Concepts of Motor Learning

- **Process** of acquiring capability for skill
- Results from experience or practice
- Can’t be directly measured; inferred from behavior
- Produces relatively permanent changes in behavior
  - Schmidt & Lee, 2005
Learning can only be assumed to have taken place when patient can perform task effectively and without thinking about it in a variety of circumstances and contexts.

Carr and Shepherd, 1982

Motor Learning Emerges from...

Newell, 1991

Performance versus Retention
Open vs. Closed Loop Systems

Schmidt’s Schema Theory

- Open-loop control and generalized motor program
- Motor programs as generalized rules for specific types of movements, or schema
  - Schmidt, 1975, Schmidt & Lee, 2005
- Predicted that variability of practice improved motor learning
- Limitations: Support is mixed for variable practice, doesn’t account for immediate acquisition of coordination

Ecological Theory

- Search strategies: search for optimal strategies to solve task, given task constraints
- Motor learning is task that increases coordination between perception and action
- Exploration of perceptual/motor workspace
- Perception: understanding goal, feedback, structures the search
  - Newell, 1991
Fitts and Posner Three-Stage Model

- **Cognitive stage:**
  - Acquisition of knowledge
  - Trial and error stage
- **Associative stage:**
  - Refining of skill
  - Less variability
- **Autonomous stage**
  - Automaticity of skill
  - Low degree of attention

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Systems Three-Stage Model

- **Key component is controlling degrees of freedom (DOF)**
- **Novice stage**
  - Simplify movement to decrease DOF
- **Advance stage**
  - Gradual release of DOF
- **Expert stage**
  - Release of all DOF
  - Vereijken, Newell, et al, 1992
Gentile’s Two-Stage Model

- Stage 1 goal: develop understanding of dynamics of task
- Stage 2 goal: Refine the movement
  - Fixation
  - Diversification

2 Phases of Learning

- Fast phase
  - Initial, fast improvements
  - Seen in single session or first few sessions
  - Activation of striatum and cerebellum
- Slow phase
  - Slow, evolving
  - Moderate gains, progressing across multiple sessions
  - Motor cortex
  - Increase in number of synapses

Components of Motor Control

- Sensation
- Perception
- Choice of movement plan
- Coordination
- Execution
- Adaptation
  - Umphred D, Neurological Rehabilitation, 2013
Sensation

• Action
  – Sensory information
  – Feedback from exteroceptors and proprioceptors

• Body Structures Involved
  – Peripheral afferent neurons
  – Brain stem
  – Cerebellum
  – Thalamus
  – Sensory receiving areas in parietal, occipital, and temporal lobes

  • Umphred D, Neurological Rehabilitation, 2013

Perception

• Action
  – Combining, comparing, and filtering sensory inputs

• Body Structures Involved
  – Brain stem
  – Thalamus
  – Sensory association areas in parietal, occipital, visual, and temporal lobes

  • Umphred D, Neurological Rehabilitation, 2013

Choice of Movement Plan

• Action
  – Use of perceptual map to access the appropriate motor plan

• Body Structures Involved
  – Association areas
  – Frontal lobe
  – Basal ganglia

  • Umphred D, Neurological Rehabilitation, 2013
Coordination

• Action
  – Determining details of plan including force, timing, tone, direction, and extent of movement of postural and limb synergies and actions

• Body Structures Involved
  – Frontal lobe
  – Basal ganglia
  – Cerebellum
  – Thalamus
    • Umphred D, Neurological Rehabilitation, 2013

Execution

• Action
  – Execution of motor plan

• Body Structures Involved
  – Corticospinal and corticobulbar tracts
  – Brain stem motor nuclei
  – Alpha and gamma motor neurons
    • Umphred D, Neurological Rehabilitation, 2013

Adaptation

• Action
  – Compare movement with motor plan and adjust the plan during performance

• Body Structures Involved
  – Spinal neural networks
  – Cerebellum
    • Umphred D, Neurological Rehabilitation, 2013
Motor Learning and Neuroplasticity...

What’s the Connection?

“Physiotherapists working with clients with musculoskeletal dysfunction conventionally evaluate region-specific movement performance or prescribe motor control exercises without considering the potential for plasticity of the CNS. In contrast, physiotherapists working with clients with neurological dysfunction commonly consider the effect of cortical dysfunction on patient performance as the brain is known to be the source of the problem.”

Snodgrass SJ et al, Manual Therapy, 2014

Learning Dependent Plasticity

- Animal model examples and human subjects examples
- Task specific motor learning important stimulant for neuroplastic change and remediation of maladaptive patterns post stroke
  - Boyd, Vidoni, Wessel, 2010
- Brain continuously remodels to encode new experiences and cause behavior change
  - Kleim JA, Jones TA, 2008
- Bottom line: skill learning leads to rewiring of motor cortex
  - Kleim JA, 2011
Reorganization in Absence of Rehab

• Compensatory behaviors key in “normal” response to brain injury
• Reliance on less-affected limb associated with reorganization and neuronal growth in non-affected hemisphere
• Can be maladaptive and interfere with relearning in affected limbs
  — Kleim JA, Jones TA, 2008

Motor Learning and Recovery of Function

• Learning is our best hope for brain remodeling
• Learning causes reorganization
• Impaired learning after multiple concussions and decreased synaptic plasticity related
  — De Beaumont et al, 2011

Recovery is a Relearning Process

• Functional improvement is a relearning process
• Brain relies on same neurobiological processes it used to acquire skill initially
  — Kleim JA, 2011
• Motor learning, not motor activity, leads to increased numbers of synapses in motor cortex
  — Kleim JA et al, 1996
Key Components of Motor Learning

- Error detection
- Conditions of practice
- Augmented feedback
- Controlling degrees of freedom
- Retention and transference