How Can I Apply Motor Learning in Orthopedic Practice?
Pathophysiology and neurophysiological processes associated with motor dysfunction in orthopedics

Dennis Fell, PT, MD. Professor and Chair. Department of Physical Therapy, University of South Alabama

R. Barry Dale, PT, PhD, ATC, OCS, SCS, CSCS. Associate Professor, Department of Physical Therapy, University of South Alabama

David Morrisette, PT, PhD, ATC, FAOMPTProfessor and Director, Division of Physical Therapy, Medical University of South Carolina

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Outline
• Introduction of motor learning integration into orthopedics. (Dr. Dale)
• Pathophysiology and neurophysiological processes associated with motor dysfunction in orthopedics (Dr. Morrisette)
• Current evidence for examining motor control (Dr. Fell)
• Principles of Motor Learning: feedback types and practice conditions (Dr Fell)
• Case-based discussion of evidence-based integration of motor learning strategies into orthopedics using cases (panel discussion)
• Final Q/A

1. Introduction of motor learning integration into orthopedics.
R. Barry Dale, PT, PhD, OCS, SCS, ATC, CSCS; University of South Alabama
• The Problem
• Context of musculoskeletal injury
  • Where we have been
  • What we know
    • Bottom-up vs. Top-down
  • What we are learning
    • Chronicity
    • Recurrence
    • Need for complete rehabilitation
  • We are going
• What goes wrong...
  • Bottom-up: Focusing solely on local tissue
    • Treating peripheral musculoskeletal conditions
    • Often driven by observable/measurable impairments
    • Is that all???
    • What about less obvious changes?
• What we are learning
  • Current Literature
    • Nervous system adaptability
      • Neuroplasticity, or re-organization, within the central nervous system
        • Inhibition
        • Excitation
        • Somatosensory alterations
        • Motor cortex
  • Chronic conditions and pain associated with them
  • Recurrent injuries
  • Need for complete rehabilitation
• How do we provide complete musculoskeletal rehabilitation?
• Local interventions
  • Traditional area of focus
• Address psychosocial aspects of patient care
• We should also address deficits within the neuromuscular system
  • Motor Control
  • Motor Learning
• Motor Control
  • Definition
    • NOT synonymous with muscle strength
    • Strength more often evaluated than motor control
    • The process by which the brain organizes and regulates action of the musculoskeletal system, including movement and dynamic postural adjustments of a joint or body segment (Dale and Fell, 2016)
• Motor Control
  • Current evidence
    • Literature describes alterations in the following joints
      • Knee
      • Spine
      • Shoulder
      • Elbow
      • Ankle
    • Specific example
      • Tendinopathy: patients often have LESS movement variability
        • Alterations of movement patterns (Rio et al. 2016)
        • Movement variability believed to minimize load accumulation in tissue
• Motor Learning
  • “An internal process that reflects the level of an individual’s performance capability and may be estimated by relatively stable performance demonstrations”. --Richard Schmidt
  • Context of rehabilitation
    “…motor skills...need to be leanred, or RELEARNED, in order for a person to achieve the goal of the skill”. --Richard Magill
• Motor Learning  
  • Mounting evidence  
    • Motor performance decrements following musculoskeletal injury  
    • Improved motor control/performance with various motor learning strategies  
      • Supplement/integrate rehabilitation paradigms  
      • Goals shift from improving strength per se, and to improve motor control  
      • Practice considerations  
      • Feedback  
        • Auditory, visual, kinesthetic  
      • Measures

• The Purpose
  • If motor deficits exist with orthopedic injury, then we should be addressing these with our rehabilitation programs  
  • Does NOT imply that we completely abandon previous strategies  
  • Rather we could/should integrate various motor learning strategies into rehabilitation programs  
  • Our other two presenters discuss the underpinnings of dysfunction more in depth (Dr. Morrisette) and specific strategies for integrating motor learning into orthopedic rehabilitation (Dr. Fell).

Section References
2: Pathophysiology and neurophysiological processes associated with motor dysfunction in orthopedics. Dr. David Morrise
tete

Objectives

- At the completion of this section, participants should be able to:
- Describe pathological models used to investigate human motor control related to musculoskeletal dysfunction/diagnoses
- Describe the current research methods used to determine problems with motor control and focus on methods involving electrophysiologic testing (H-reflex, transcranial stimulation for cortical thresholds and mapping) and imaging (fMRI)
- Summarize the current findings in the literature using the ankle and knee as examples of areas of investigation
- Apply knowledge concerning neuroplastic changes following injury towards recognition of functional deficits during clinical examination

Neuroplasticity

The focus of recent research surrounds translational projects aimed at enhancing clinical outcomes.
Knowledge of mechanisms underlying this adaptability is the foundation for our treatments, diagnoses, and prognoses.
The increasing understanding of the mechanisms underlying neuroplasticity can guide, direct, and focus the practice of current and future therapies to greater efficacy and better functional outcomes in clinical rehabilitation


Models used to study disrupted motor control in the orthopedic literature

The typical situation to study motor control in the musculoskeletal literature has been with “instability”
Various terms and constructs are used:

Static stability
Dynamic stability

Segmental instability
Radiographic instability
Clinical instability
Functional instability

Depending on the context, the same behavior can represent a stable situation or a situation of correcting for instability
**Stability**

“Stability, one could argue, is a term that appears to change depending upon the context, and as such, appears to have unstable definitions.” (Reeves, et al. 2007)

“There is no absolute definition of stability” (Reeves and Cholewicki, 2003)

Stability depends on the system and the task being performed.

**Lesson from the “six blind men and the elephant”**

Objects/situations are either Stable or Not stable

No degrees of stability

Reeves NP, Narendra KS, Cholewicki J. Clinical Biomechanics. 2007

- Situations:
  - Stable and robust to perturbation
  - Stable but not robust to perturbation
  - Not stable

When we review the literature, we may well not be looking at the same musculoskeletal problem or pathology (“instability”) across studies, although the same or a similar label is used.

Need to know operational definition used.

Many variables can influence motor behavior/control (*pain, effusion, acuteness/chronicity, prior injury, prior training/level of performance, age, fatigue*)

Deandrade JR, Grant C, Dixon AS. J Bone Joint Surg Am. 1965:47;313–322

Spencer JD, Hayes KC, Alexander IJ. Arch Phys Med Rehabil 1984:65;171-7

**Measurement tools used for physiological processes in the nervous system**

Used to investigate neuroplasticity, the ability of the nervous system to change (remodel or reorganization) in response to a behavior (task) or insult

**H-reflex**

Evaluation of the excitability of alpha motor neuron pool

Stimulate motor and sensory nerve

Deep tendon reflex, electrically induced

  - Expressed as a ratio to the M response.

H:M ratio.

Can determine enhanced excitability or lowered excitability of alpha motor neuron pool.

Frigon A, et. al. J Neurophysiology. 2004
Transcranial stimulation (TMS)
Transcranial magnetic stimulation (TMS)
- Used as an investigation tool
- Uses as an intervention tool
- Pioneered in the investigation of neurological pathology and now in the treatment of neurological pathology
Stimulate the motor cortex and measure the motor response in a particular region (EMG recordings from muscle(s))
Evaluate for threshold and size of area producing a response
Resting motor threshold (RMT)
- Minimal stimulus required to get a minimal twitch from the muscle of interest while at rest
Active motor threshold (AMT)
- Minimal stimulus to gain a minimal twitch from the muscle of interest while the muscle is isometrically contracting at a standardized level (usually 10% MVC)

Functional MRI
Used to examine for areas of the central nervous system (typically the brain) that are active during a particular paradigm
Results dependent on the brain’s blood oxygen level (cortical oxygen demand)
Used for cortical mapping among other uses

Other methods
Ability of participants to control posture while performing a task
Levels of muscle activity (EMG) in relation to EMG from a maximal volitional contraction, while performing specific tasks
Levels of maximal voluntary activity versus maximum evoked contractions with electrical stimulation (recruitment)

Sample of Studies Involving the Ankle (lateral ankle sprain model)
   Functional ankle instability (FAI)
   Force plate and EMG measurements
   Center of pressure shift laterally (foot is more inverted from 20% to 90% of the stance phase)
Peroneus longus (fibularis longus) activation was greater at initial contact and terminal stance with functional instability.

Peroneus longus activity was lower during 20% to 40% stance in the FAI group.

No difference in tibialis anterior activity.

Kinematic and kinetic analysis of early stance phase
Chronic ankle sprain participants (CAI) where more inverted (60 to 70) compared to controls (N = 25 chronic ankle instability, 25 age matched controls)
CAI participants inverted at initial contact at a faster rate than controls everted during initial contact.

Premotor, motor, and reaction time in individuals with CAI
- Reaction time = time from stimulus to muscle response
- Premotor time = information processing in the CNS
- Motor time = initiation of the response to completion
Auditory and visual stimulus to trigger a jumping response
Premotor time was longer for peroneus longus (PL) in the non-injured LE
Motor time of PL was significantly shorter in the non-injured LE
No statistical significance with gastroc-soles, tibialis anterior

12 participants with CAI, 12 controls
Reaction time for ankle eversion and ankle dorsiflexion in reaction to an auditory stimulus
Reaction time slower on the involved side and compared to the control group for peroneus longus, due to increased motor time but not pre-motor time
No statistical difference with anterior tibialis.

Basketball players with FAI (n=10) compared to non-instability (n=11) and non-sports control group
Sudden ankle inversion platform with force plate and EMG
Increased reaction time for fibularis longus in the FAI group and non-sports group
Increased reaction time for tibialis anterior between the FAI group and the non-instability group
Muscle reaction time is faster in athletes than in non-athletic group (mean = 20 ms.)

-12 individuals with FAI (CAIT < 25) and 12 controls (tested for laxity with instrumented ankle arthrometer)
No significant differences in laxity between groups
Measured cortical excitability and inhibition with TMS
Control group demonstrated relationship between less anterior displacement and greater TA excitability.
Higher inhibition related to greater laxity.
FAI group had relationship between higher anterior displacement and higher soleus excitability; greater inversion displacement and higher peroneal excitability.
"Compensation by relying on greater excitability"

   -10 people with CAI, 10 controls
   TMS over the motor cortex for fibularis longus, resting motor threshold (RMT)
   Higher thresholds for fibularis longus in the injured and uninjured sides in the CAI group
   Lower RMT correlates with lower self-reported function

   -21 individuals with CAI and 24 controls
   H-reflex testing and TMS testing
   Motor evoked potentials (MEPs) where greater in the control individuals for fibularis longus
   (both cortical and at SC level).
   No difference for VMO excitability with TMS or H-reflex

   Used H-reflex to investigate motor-neuron pool excitability (MNPE) in acutely injured ankles (N = 10 athletes) and healthy group (N = 10)
   Soleus, fibularis longus, tibialis anterior
   No differences side to side in healthy group
   Soleus MNPE was higher in the injured ankle
   Anterior tibialis MNPE tended to be lower in the injured ankle (p=.06)

Summary for the ankle
Differences in kinetics and kinematics of gait
Differences in cortical excitability
   -Muscle dependent
   -Commonly increased cortical excitability for some ankle muscles when acute, decreased when chronic
Differences in neuronal pool excitability acutely and with chronic problems
Differences in motor planning (pre-motor time) and changes in reaction time
Peroneus longus is the most consistently involved muscle out of those evaluated, not all ankle muscles have been investigated
Non-involved side may be affected with chronic problem

Knee model, ACL injury (including post rehab and post surgery)

   Case control study, one individual before second ACL repair and one with no history of LE injury
   fMRI data during active knee movement were compared individuals ACL injured individual demonstrated increased activation of the motor planning, sensory-processing, and visual-motor control areas of the brain
   Similar changes found for the non-involved side
   *Difficult to interpret findings with one subject and one control
ACL injured individual demonstrated increased activation of the motor planning, sensory-processing, and visual-motor control areas of the brain
Similar changes found for the non-involved side
*Difficult to interpret findings with one subject and one control

Central activation ratio (CAR) for quadriceps following ACL reconstruction (electric twitch imposed over maximum contraction)
-53 individuals with ACL repair and 50 individuals with no history of LE injury
In the ACL-R group, CAR and the IKDC scores were lower than in the control group.
Torque variability was greater in the ACL-R group

-22 individuals with ACL-R and 24 controls
ACL-R group:
Greater asymmetry in knee extension torque
Reduction in quadriceps Central Activation Ratio (CAR)
Increase in quadriceps active motor threshold (AMT)

Measured corticospinal excitability, spinal-reflexive excitability, strength, and voluntary activation prior to, 2-weeks post, and 6-months post ACL-R
-20 individuals with ACL-R, longitudinal case-control with 20 “healthy” controls
ACL-R demonstrated bilateral reductions in spinal-reflexive excitability compared to controls, pre-surgery and 2-weeks post-surgery
ACL-R demonstrated higher AMT at 6-months post-surgery in both LE’s
Central activation ratio was lower in both LE’s in ACL-R at 6-months

Case control study
TMS to examine active motor thresholds (AMT) for vastus medialis H-reflex for quadriceps
-28 individuals with unilateral ACL-R and 29 controls
AMT was higher in the injured than uninjured limb in the ACL-R group suggestive of corticomotor changes
Greater excitability (H:M ratio) in the ACL-R group
ACL-R with higher voluntary activation threshold had the higher H:M ratio

Summary
Using ankle sprain and ACL repair models, several themes emerge regarding motor control
Acute
- Threshold for alpha motor neuron pools may lower for certain muscles surrounding the affected joint
- Threshold for the motor neurons for muscles remote to the joint have not yet been shown to be affected, but very few muscles have been studied
Chronic
- Possible cortical reorganization
- Altered thresholds for cortical neurons and alpha motor neurons
- Alpha motor neurons for some muscles appear to compensate for lowering of cortical excitability

Changes involve cortical (?) and spinal cord neurons.
Excitability most likely does not return to previous levels as time passes.
How to provide the best intervention to improve neural organization and activity is yet to be discerned.

Section References
Deandrade JR, Grant C, Dixon AS. J Bone Joint Surg Am. 1965:47;313–322
Reeves NP, Narendra KS, Cholewicki J. Clinical Biomechanics. 2007
Frigon A, et. al. J Neurophysiology. 2004
Grooms DR, et al. J Athl Train. 2015 (2 manuscripts)
3. Current evidence for examining motor control and principles of Motor Learning: feedback types and practice conditions
Dennis W Fell, PT, MD

- Observation of Motor Control
  - Smooth, continuous, flowing...
  - Selective control (isolated movement as indicated by the task)
  - Accuracy
  - Speed (variability)
  - Initiation/cessation (grading-on/grading-off)
  - Ex: ankle d'flex – concentric and eccentric control – TRY IT!
  - Motor Skill Performance Outcome Measures vs Performance Production Measures

- Kinematic Measures
  - “the description of motion without regard to force or mass” (Magill, 2014)
  - 2-D or 3-D Movement analysis
    - Displacement
    - Velocity
    - Acceleration
  - Put them all together to describe the linear or angular motion

- Kinetic measures
  - “consideration of force in the study of motion... force as a cause of motion” (Magill, 2014)
  - External sources of force can be measured: gravity, air resistance, water resistance
  - Internal sources of force can be measured: muscles force can be used to push or pull
  - ... can get very complicated

- Physiologic Measures Related to Motor Control
  - Muscle:
    - EMG
    - wMMG (whole muscle mechanomyography)
    - NIRS (near infrared spectroscopy)
  - Brain Activity:
    - EEG
    - PET
    - fMRI
    - MEG (magnetoencephalography)
    - TMS (transcranial magnetic stimulation)

- Clinical Smartphone/Tablet Applications
  - Hudl Technique
    - including slow motion replay
    - Freeze-frame
    - On-screen angle measures
Clinical Smartphone/Tablet Applications

Smartphone accelerometry

NEUROPLASTICITY AS BASIS FOR MOTOR LEARNING

- A vision for expecting Neuromotor change:
- Once, people thought that the person with CVA or brain injury was “stuck” with their condition of the brain after injury,
- Early in our profession, PTs thought that we can help the person improve by teaching them to “get by” using alternate movement strategies, not expecting any real physical improvement.
- the brain can change (new cells, new synapses, new interconnections), but still we thought our role was to simply take advantage of the positive change
- Next, we understood that the brain can change, and that some interventions we provide may be related to more significant functional improvement (even in Chronic CVA –even YEARS after the injury, given appropriate environment and stimulation.
- Finally, we are beginning to understand that we actually help to create and drive the positive neuroplastic change! Actually CAUSES the positive, experience-dependent neuroplastic change!!!!!!
- the problem-solving inherent in doing something different is what drives neuroplasticity; also applies in generating cognitive neural plasticity (Merzenich, 2006)
- the real goal is to generate neuroplasticity – DON’T JUST JUMP ON THE TRAIN; DRIVE THE TRAIN!!!

Process/Distinctions

- Motor Learning – “a set of processes associated with practice or experience leading to relatively-permanent changes in the capability for skilled behavior.” i.e., motor behavior that results from practice, experience, feedback... (Schmidt, 1988)
- Neuroplasticity is the positive change that happens in the CNS (and the process that leads to that change) to allow the change in capability
- Improved Motor Skill/Behavior ?see??
- So Motor learning and Neuroplasticity are both process (can only be seen implicitly in the change that results).

Practice/Experience

![Diagram showing the relationship between practice/experience, neuroplasticity, motor learning, and improved skilled behavior.]

Neuroplasticity (in CNS)
-> PROCESS ->
Motor Learning or Relearning
(in neuro-sensorimotor interactions)

Observe/Measure Improved Skilled Behavior:
Brain-derived neurotrophic factor (BDNF) (see review Mang, 2013)
- a neurotrophin protein involved in neuroprotection, neurogenesis and neuroplasticity
- a key mediator of motor learning
- aerobic exercise induces up-regulation of BDNF (Cotman, 2002 & 2007)
- the up-regulation of BDNF stimulates neuroplasticity/recovery (Lambourne, 2010; Kramer, 2006; Kluding, 2011; Rand 2010)
- disrupting BDNF synthesis or blocking it in the CNS diminishes training-induced plasticity (VandenBerg, 2004)
- no direct evidence in humans because of invasive intracortical injections (Mang, 2013)
- human systemic levels of BDNF elevated for 10-60 min following aerobic exercise (Knaepen, 2010), and increase in basal levels (Seifert, 2010)
- aerobic exercise increases BDNF gene expression in hippocampus, cerebellum, cerebral cortex, and spinal cord
- BDNF Val-Met Polymorphism is associated with poorer outcomes (less plasticity), associated with less brain activation following stroke! (Kim, 2016 Phys Ther)

PRINCIPLES OF MOTOR LEARNING: FEEDBACK and PRACTICE CONDITIONS
- Dennis W Fell, PT, MD
- Acknowledgment to Blair Saale DPT, NCS

Two Types of Feedback

- **Intrinsic (Inherent)**
  - Inherent in task itself
  - e.g. proprioception, kinesthesia, visual, auditory, cutaneous, vestibular

- **Extrinsic (Augmented)**
  - Supplementary feedback about the task
Two Types of Augmented Verbal Feedback (Extrinsic)

Extrinsic

Types

Knowledge of Performance (KP)
Info about form/quality of movement
Extremely important

Knowledge of Results (KR)
Verbal post-movement info about movement outcome
May form initial reference of correctness
If KR delay interval is too short \(\rightarrow\) less learning
Don’t fill with activities!
Precise info for adults initially, not for kids

Timing of Extrinsic Feedback

Extrinsic

Characteristics

Timing

Concurrent

Delayed

Terminal
Case Discussions and Notes: