Neurocognitive & Motor Control Strategies in ACL Rehab: From the WHAT to the HOW

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Introduction & Background

Session Objectives
- Recognize the discrepancies between the requirements of successful sports performance and the typical rehabilitation environment
- Understand how neurocognitive and neuromuscular deficiencies prohibit successful recovery and return to activity after ACL injury and reconstruction
- Develop and employ effective and sport specific exercise parameters to build the foundation for a successful return to sport
- Learn and implement new clinical strategies for addressing specific neurocognitive and neuromuscular performance deficits to maximize success in ACL rehabilitation

ACL Reconstruction and Return to Sport
- 55-83% of athletes return to sport (RTS) after ACLR (Ardern 2014, Lai 2018)
  - % may be lower within one year from ACLR
  - Reduced performance upon RTS
- Almost 30% of athletes sustained a 2nd injury less than 24 months following primary ACLR and RTS (Paterno et al 2014)

As clinicians, the important question to ask ourselves is:

How can we do a **BETTER** job of ACL Rehab to allow athletes to return to pre-injury level of sport while minimizing re-injury risk?

Comparing Sports Environment vs Typical Clinical Environment
- **Sports**
  - External focus of attention
  - Focus on task outcome, not movement mechanics
  - Rapid, responsive, changing
  - Reactionary
- **Clinic**
  - Internal focus of attention
  - Manual & visual feedback of mechanics
  - Slow, controlled, sustained
  - Pre-planned
Part 1: Athletic Movement for Return to Sport after ACLR

Objectives

- What is athletic movement?
- Why is athletic movement an important concept in ACL rehab?
- How can rehab techniques optimize the recovering and development of athletic movement?

Athletic Movement

- Opposition of arms and legs
- Multi-joint movement
- Triple flexion
- Triple extension
- Multi-planar with emphasis on rotation
- Quick changes of base of support
- Unsupported
- Unanticipated movement
- Indirect contact

Recovering Athletic Movement

- Preparing properly
- Emphasize learning
- Optimize feedback for the patient not the PT
- Focus of attention for retention
- Optimize timing of feedback and practice

Sources of Feedback

- Intrinsic
- Extrinsic

Types of Feedback and Skill Acquisition

- Manual
  - Creates dependency and reduces retention
  - Should only be used for safety and very low skill performers
- Visual
  - Motor areas involved in preparation and execution of action is activated by observation (Calvo-Merino 05, Bellelli 2010)
- Verbal
  - Focus of Attention
    - IFOA (Explicit learning)
      - Direct attention toward the body’s components during a task
    - EFOA (Implicit learning)
      - Direct attention toward external effects of action or the goal
      - Several studies have shown improved performance and retention with motor skills and athletic movement performance.
      - Emerging research related to ACL injury prevention and rehabilitation.
• Delayed Feedback
  • Encourages problem solving and discovery
  • Leads to greater retention
• Bandwidth Feedback
  • Less feedback can mobilize cognitive processes for performance (Chambers 06)
  • Improves performance (Goodwin 1995)
• Blocked vs. Random practice
  • Random practice of a motor skill enhances long term learning more than blocked (Overdorf 04)

References - Part 1


References - Part 1 (Cont.)


References - Part 1 (Cont.)


Part 2: Rapid Muscle Activation & Force Development

**Objectives**

- **Recognize** the importance of rapid muscle activation & force development to athletic movement
- **Understand** how ACL injury & reconstruction influences neuromuscular function
- **How** to train for rapid rate of muscle contraction through specific dosage of therapeutic exercise while respecting healing constraints post-ACLR

**Muscle Performance after ACLR**

- Quadriceps neuromuscular dysfunction
- Poor Quad function alters movement mechanics, increases re-injury risk, has potential to impair sports performance
- Quad and LE strengthening is a fundamental component of ACLR rehab
- Quad Assessment - Typically quantified as maximal strength
  - 85-90% LSI for RTS
  - Persistent dysfunction even with recovery of quad strength symmetry

**Why “Rate” is Important**

- Neuromuscular activity (activation of motor units to produce muscle contraction) during typical human movement is characterized by bursts of muscle activation
- Muscle rapidly turns “on”/“off”, resulting in rapid increases and decreases in force production
- Typical human movement involves repeated patterns of rapid muscle activation and relaxation producing rapid modulations in muscle force production
- Speed of typical human movement precludes peak muscle force development during most daily and sports activities (in most cases, 200 ms or less)
Quadriceps Activation patterns during typical movements
- Walking
- Jogging
- Running
- Leaping
- Cutting
- Changing Directions
- Movement Sequences w/transitions

Quadriceps Rate of Force Development and Rate of Activation after ACLR
- Rapid quadriceps force development / lower extremity muscle power asymmetries may be greater than strength asymmetries post-ACLR (Angelozzi 2012, Knezevic 2014, Mirkov 2016, Neeter 2006)
- Muscle Power / rate of torque development may be more important to recovery of movement biomechanics than maximal strength post-ACLR (Blackburn 2016, Kline 2015, Pua 2018)
- UW Athletics: Significant asymmetries in knee extensor rate of torque development and quadriceps rate of activation during sports activities 6 and 9 months post-ACLR

Are we appropriately addressing muscle speed/power in ACL Rehab?
WHEN do we perform fast muscle contractions post-ACLR?

Recovery following ACL injury & surgery
- People are more sedentary/protective of the injured limb
- Low intensity exercises (QS, SLR) performed with slow ramp contraction
- Potential for neuromuscular inhibition limiting both muscle recruitment and rate coding

Quadriceps Activation Patterns during Rehabilitation
- Consider the typical activation patterns and compare when there is a specific focus on speed of contraction
  - Quad Set
  - Mini Squat
  - Forward Lunge
  - Seated Knee Extension
  - Weight shifting
  - Single Leg Squat
  - Lateral lunge
  - Leg Press

Inducing Rapid Activation Adaptations
- Keys to training rate of activation:
  1) Intent
  2) Instruction

Review & Summary
- Consider demands of sport when selecting parameters & dosage of rehabilitation interventions
- Need muscle strength and power to perform sports activities safely and effectively
- If we don't provide patients with the tools to move effectively, we are setting them up to fail
References - Part 2


References - Part 2 (Cont.)


References - Part 2 (Cont.)


Part 3: Neuroplasticity

**Objectives**
- Traditional rehab focus
- What is neuroplasticity
- Why is neuroplasticity an important concept in ACL rehab
- How does ACL injury affect neuroplasticity and movement
- How can we incorporate this concept into training and a rehab program

Return to Sport (Ardern et al. 2014)
- Of athletes recovering from ACL reconstruction:
  - 81% of people returned to any sport
  - 65% returned to preinjury level
  - 55% returned to competitive level sport after surgery
- How can we improve these outcome percentages??

Traditional Rehab Focus
- Regain full knee range of motion, normalize gait, eliminate effusion
- Restore quadriceps activation and strength
- Knee control and core stability
- Proprioception
- Neuromuscular control*
Definition: motor output in response to afferent/sensory input OR precise muscle activation that allows for a coordinated and efficient action

- Low to high-level athletic activities and sport specific movements to progress an athlete back to sport
  - Need to mimic sport with goal of creating long term quality athletic movement

**Are we optimizing the last two principles? If not, how can we improve?**

Three Balance Systems

- Sensory input
  - Vestibular
  - Visual
  - Proprioceptive
- Input integration
  - Cerebellum
  - Cerebral cortex
  - Brainstem
- Motor output
  - Vestibulo-ocular reflex
  - Motor impulse

Neuroplasticity

- Ability of the brain to form and reorganize synaptic connections, especially in response to learning or experience or following injury
  - Positive → in response to learning
  - Negative → in response to injury
- ACL injury → Sensory neuroplasticity (altered somatosensory input and processing) → Proprioception (decreased joint position sense for motor control) → Motor neuroplasticity (altered efferent output, more planning/visual processing needed) → Postural control (diminished unless increase in vision/planning) → NM Control (visual and cognitive reliance for movement) (Grooms et al. 2015)

Research Supported Findings

- Kaprelli et al. 2009
  - Compared 17 males with right ACL rupture to 18 matched controls >6 months since injury (no reconstruction)
  - Performed active knee flexion and extension (0-45°) during an fMRI scan
  - Results:
    - Primary sensorimotor area → proprioception and sensation
      - Decreased in ACL group
    - Presupplementary motor area → motor planning
      - Increased in ACL group
    - Inferior temporal gyrus → visual processing
      - Increased in ACL group
- Grooms et al. 2017
  - Similar to Kaprelli but compared 15 subjects post ACLR vs controls
  - fMRI scan taken during active knee flexion and extension
  - Results:
    - Increased in ACLR group
• CL Primary Motor Cortex → movement
• IL Lingual Gyrus → processing visual and sensory feedback
• IL Secondary Somatosensory Cortex → processing sensory stimuli and pain
  ▪ Decreased in ACLR group
• IL Motor Cortex → movement
• IL Vermis → coordination/timing of movement

What Could This Mean For Recovering Movement (Grooms et al 2015, 2017)
• Decrease excitability motor cortex
  ▪ Increase processing demands for simple movement
• More visually based strategy for movement
• Activation of higher level sensory integration area
• **Unilateral training may further drive neuroplastic changes**

Clinical Application
• Why might these altered strategies for recovering movement be problematic??
  ▪ Adaptation mechanisms become overloaded in an athletic environment
• Is rehab promoting these neuroplastic changes??
• Classic Rehab
  ▪ Focus of attention
    ▪ Usually fully on the movement
    ▪ In sport focus is on the environment not the movement
  ▪ Increased visual and cognitive strategies promoted in therapy
    ▪ i.e. mirror feedback, “think about keeping your knees out”

Strategies
• External focus of attention with cueing
• Direct Visual Disruption
• Indirect Visual Disruption

Direct Visual Disruption
• Postural Sway increases with ACL injury (Okuda et al. 2005)
  ▪ Eyes closed
  ▪ Injured leg SLB but not uninjured
• Systematic review (Negahban et al. 2014)
  ▪ Balance deficits B with eyes closed post ACL
• Easiest Way to disrupt visual system?
  ▪ Close eyes
• Limitation to closing eyes?
  ▪ Activity must stay relatively static (sport is dynamic)
• Making visual disruption more dynamic
  ▪ can include obstacles, targets, reaction
  ▪ Specific examples:
    ▪ Single leg balance vs single leg balance with ball toss
    ▪ Bounding with movement (step cross-over bound)
    ▪ Hopping over hurdles
Indirect Visual Disruption

- Targets
- Reaction
- Dual task
- Other players
  = anything to increase task complexity and cognitive load
- Research (Ford et al. 2005)
  - Overhead goal changes performance and mechanics with drop vertical jump
    - Jump height
    - Stance time
    - Hip moments
    - Knee & ankle angles
  - Movement changes with use of a target – why?
    - Due to focus of attention elsewhere?
      - Want to ensure athlete has optimal quality of movement when focus placed elsewhere
    - Increased effort with targets and goals?
      - Effort may drive movement quality post ACLR (i.e. jump at 50% effort vs 100%)
- Targets & Reaction
  - Examples: movement with reactive and targeted reaching outside base of support
    - Squat, lunge, jump
  - Examples: movement with reaction (stimulus initiates movement or requires a change in movement)
    - Jump, hop, run, lateral change of direction, cut/pivot
    - Can be in response to something visual (i.e. reacting to a light or another person), audible (i.e. clap)
- Dual Task
  - Examples: ball tossing, different colors, stating months backwards
    - Can be physical or cognitive

When to Implement?

- Start immediately
  - Examples: focus of attention when doing a quad set, ball toss with straight leg raise

Part 3 Summary

- Majority ACL research on biomechanics
  - Neuroplasticity and need to consider what’s going on cognitively
- Altered somatosensory →
  - Reliance on vision and higher cortical processes
- Get out of traditional rehab strategies
  - Recreate the environment
References - Part 3


