Athletes Have Brains Too: A Neuro-Sports Collaboration on Motor Learning

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No Disclosures

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Objectives

- Describe the Latest Research in Motor Learning Principles and its Implications for both Neurorehabilitation and Sports Physical Therapy Practice
- Differentiate Historical and Modern Approaches to Motor Learning used in Sports Physical Therapy
- Apply Motor Learning Strategies to Diverse Case to Highlight the Shared and Distinct Considerations for Both Programs
- Identify Opportunities to Integrate Neuro and Sports Physical Therapy Expertise to optimize Patient Outcomes in Motor performance and Learning

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Why Motor Learning is valuable in Sports?

Study / Year	Population/Sport	Neuro Concept	Design/Type	Key Finding (very short)
Thomas et al., 2024 (IJSpt Part 2)	Post-ACLR athletes	Neurocognitive elements in rehab & RTP testing	Clinical commentary	Proposes integrating neurocognitive training into late-phase ACLR rehab to reduce re-injury risk and improve RTP testing.
Frontiers Hum Neurosci, 2023	ACL injured/ACLR	Sensorimotor cortical organization changes	Narrative review	ACL injury/reconstruction involves CNS changes affecting both limbsâ€"supports neuro-informed rehab.
Brain Research, 2024	ACL injured	Brain functional connectivity alterations (fMRI)	Imaging study/review	Demonstrates brain adaptations after ACL injury/reconstruction.
Grooms et al., 2015 (JOSPT)	ACL injured	Neuroplasticity & visuomotor training	Perspective/Review	Advocates visual-motor & neurocognitive approaches with neuromuscular rehab after ACL injury.
Brain Sciences, 2025	ACL injury (sex differences)	Cortical activation & neuromuscular regulation	Review	Highlights neurophysiological distinctions and the need to integrate sex as variable in neuro-informed ACL research.
Sports Med, 2025	Athletes (COD tasks)	Anticipation & dual-tasking effects	Systematic review	Dual-task/anticipation alters knee-injury-related biomechanics; suggests adding cognitive challenges to screening/training.
PeerJ, 2024	Team sports (jump-landing)	Dual-task or sport-specific constraints	Systematic review	Cognitive load during testing affects biomechanical risk metrics; conventional tests under-load cognition.
J Appl Biomech, 2025	Healthy athletes	Dual-task drop jumps	Experimental study	Adding cognitive tasks to DVJ changes ACL-risk biomechanics.
Wulf, 2013 review	Various skills incl. sport	External vs internal focus	Review	External focus consistently enhances motor learning/performanceâ€"relevant for rehab cueing.
Wulf et al., APA meta-analyses	Various	External focus superiority	Meta-analyses	Meta-analytic evidence that external focus improves performance & learning.
PTJ, 2000 (Fitzgerald et al.)	ACL deficient (non-op)	Perturbation training (sensorimotor)	Randomized trial	Perturbation added to standard rehab improved function/return to activity.
Knee, 2023	ACL tear	Perturbation-based balance training	Systematic review	Supports PBBT to improve neuromuscular control post-ACL injury.
BMJ, 2009 (Hupperets et al.)	Athletes with prior ankle sprain	Home-based proprioceptive/neuromuscular training	Randomized trial	Reduced recurrent ankle sprains with unsupervised proprioceptive training.
J Clin Med, 2025 (MDPI)	Soccer players	Neuromuscular training for injury prevention	Systematic review	NMT reduces lower-limb injuries; adherence/coaching key.
J Orthop Surg Res, 2025	Soccer players	Balance training in injury-risk reduction	Meta-analysis	Programs incl. balance work reduce ACL injuries.
Frontiers Physiol, 2017	Youth athletes	Doseâ€"response of NMT	Meta-analysis	Identifies frequency/volume parameters for NMT to cut injuries.
BJSM, 2015	Young females	Specific exercises within NMT	Systematic review	Highlights which NMT elements most relate to ACL injury reduction.
BJSM, 2015 (FIFA 11+)	Football (soccer)	Structured neuromuscular warm-up	Evidence summary	FIFA 11+ effectively reduces injuries; scalable neuro-motor program.

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Define:

- Neuroplasticity
- Motor learning
- Neurocognition

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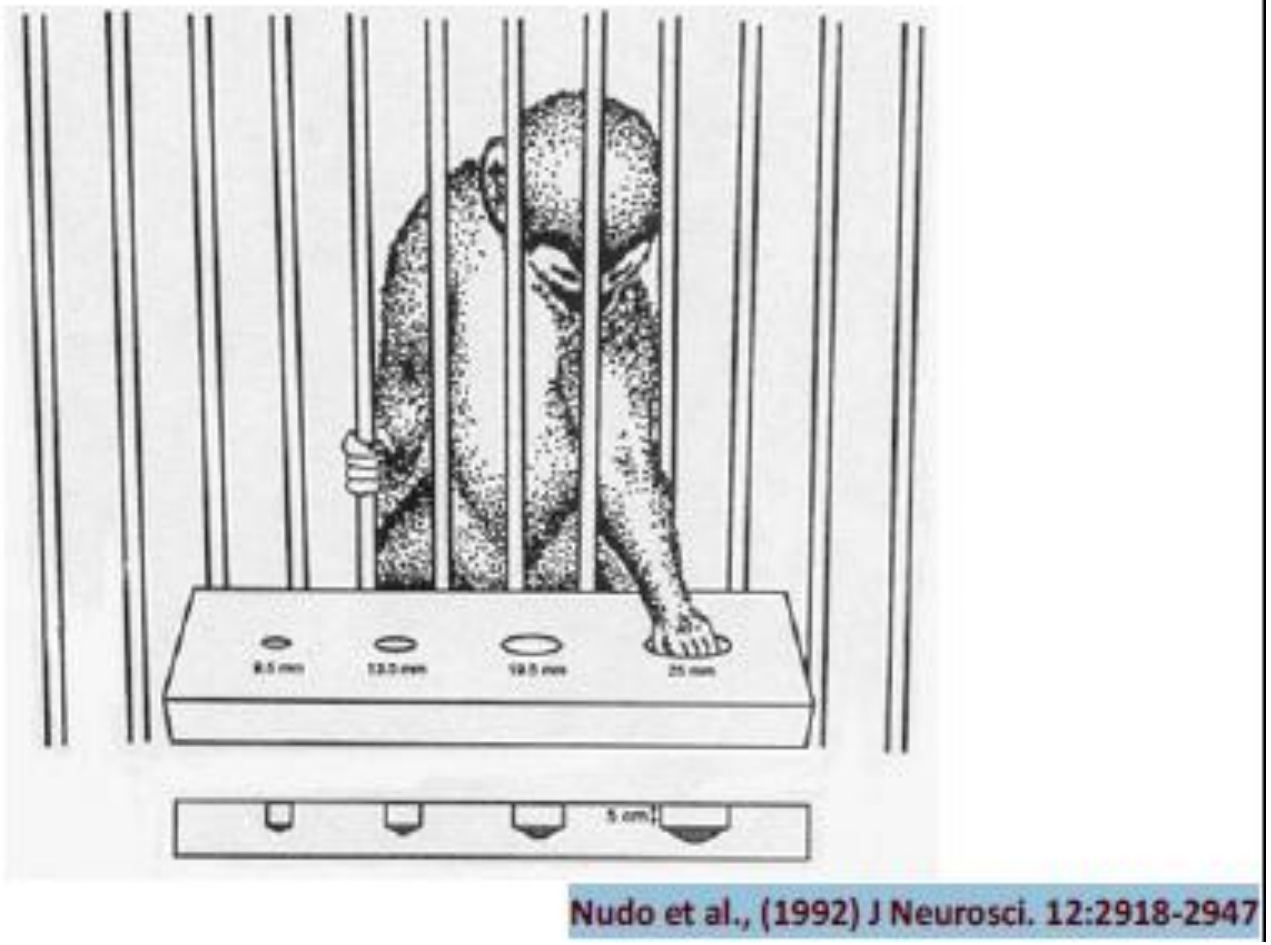
The Beginning....

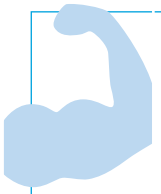


Nudo et al., (1992) J Neurosci. 12:2918-2947

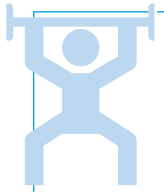
Neuroplasticity

“The ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function, and connections.”

Neuroplasticity Principles

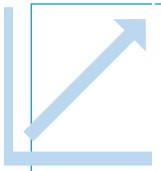


Use it or Lose it

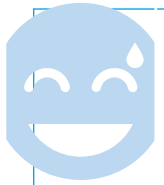


Use it and improve it

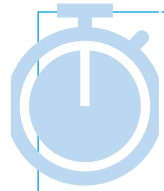
Specificity



Repetition Matters

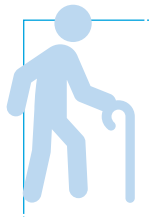


Intensity Matters

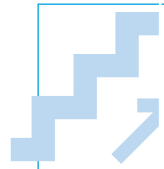


Time Matters

Salience Matters



Age Matters



Transference

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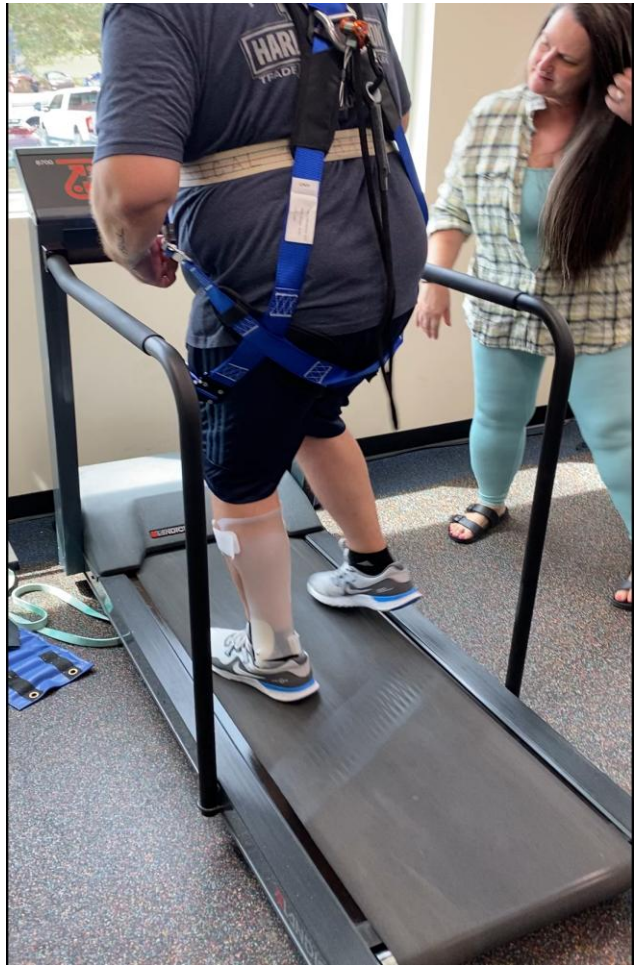
Neuroplasticity



What is Motor Learning

- “A set of processes associated with practice or experience leading to relatively permanent changes in the capability for movement"

- Key Areas of the Brain:
  - Primary Motor Cortex
  - Prefrontal Cortex
  - Basal Ganglia
  - Cerebellum
  - Parietal Cortex

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Motor Learning Updates

Mechanism	Historical Use	New Understanding
Use-dependent learning -- Motor Cortex	Widely applied	Reinforced with neuroplasticity models, but alone is insufficient for full recovery
Instructive Learning -- Prefrontal Cortex	Traditionally dominant (e.g. giving cues)	Shown to work best when combined with other mechanisms; relies on conscious strategy
Reinforcement Learning -- Basal Ganglia	Rarely Emphasized	Now recognized as critical- driven by reward/success, involves basal ganglia
Sensorimotor Adaptation -- Cerebellum	Often Overlooked	Implicit recalibration using sensory error; cerebellar-driven and vital for fine tuning

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Motor Learning Mechanism

Mechanism	Example Strategy
Use-Dependent	High-reps; effortful task practice
Instructive	Direct verbal or visual cues adjusting movement strategy
Reinforcement	Providing immediate feedback/rewards for correct performance
Sensorimotor Adaptation	Training with error-inducing perturbations requiring predictive adjustment

Measures of Motor learning

Automaticity

- Improved efficiency, reduced need for conscious attention, and adaptability under different conditions

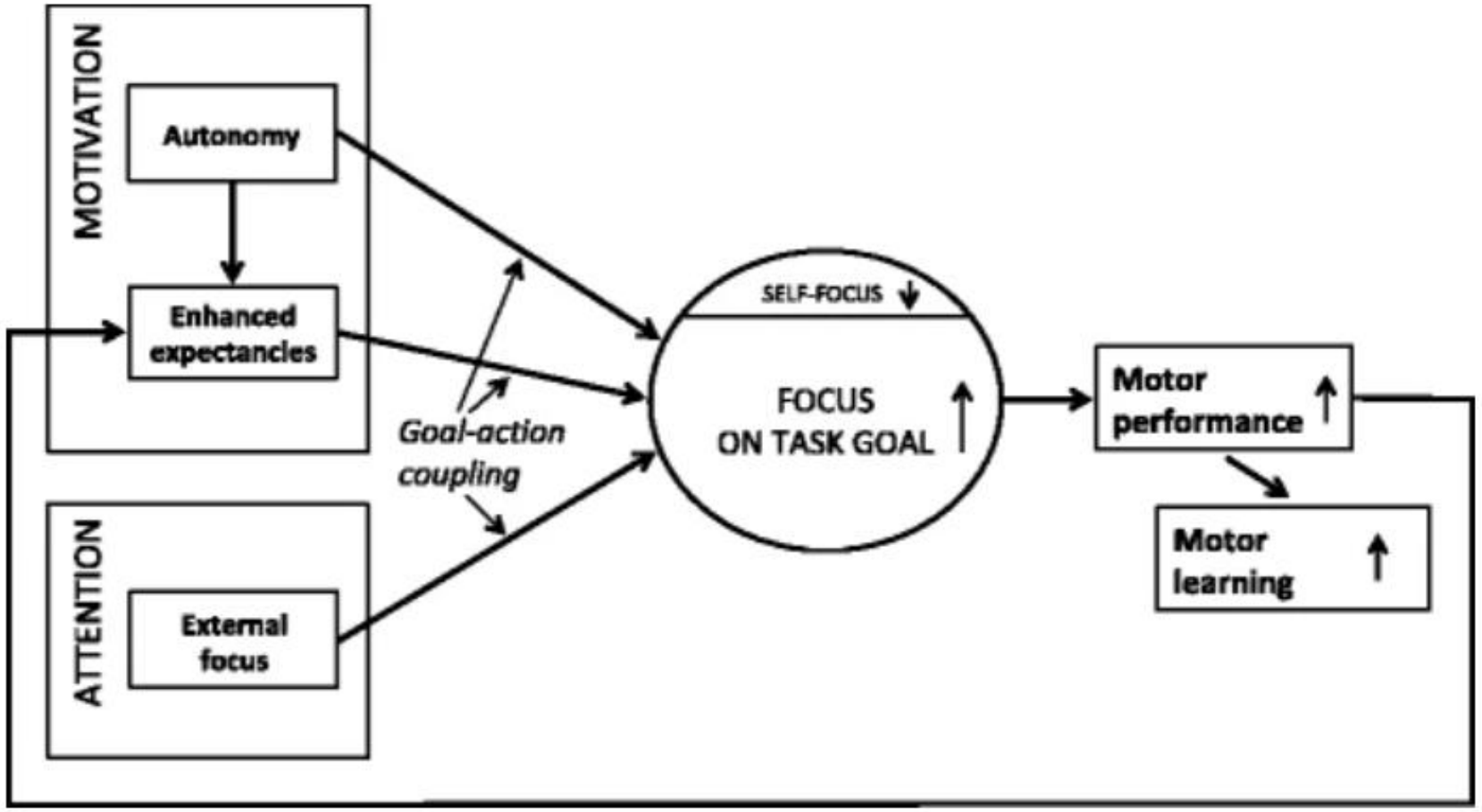
Retention

- Ability to perform skill after a period of no practice

Transference

- Ability to apply what was learned to other similar tasks

Optimal Motor Learning Theory



Optimal Motor Learning Theory

- Autonomy
  - Individual's perception that they have control and choice in the learning process
- External Focus
  - Directing attention to the intended effects of the movement on the environment, rather than to the movement of one's own body
- Enhanced Expectations
  - The belief or confidence that one will succeed in the task

OPTIMAL and Neuroplasticity in Practice

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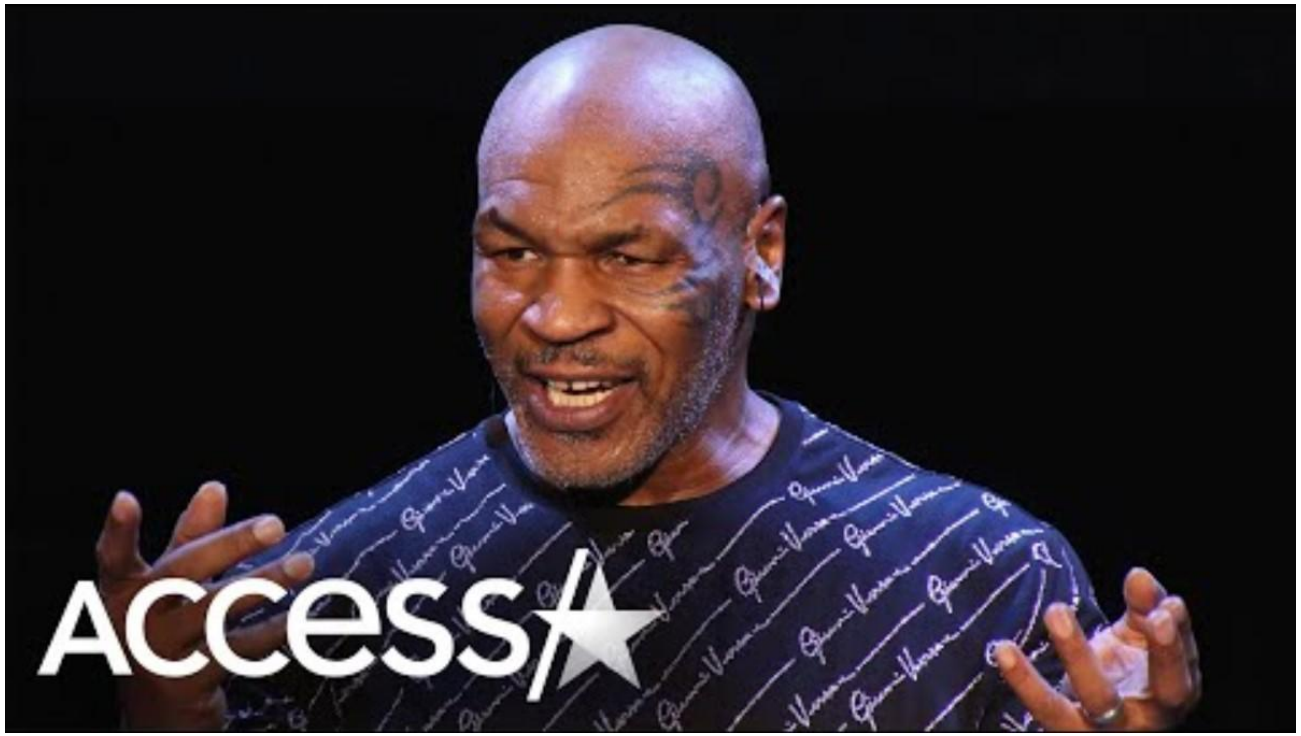
Speech Therapy in PT: Why you need us

- The role of the speech therapist



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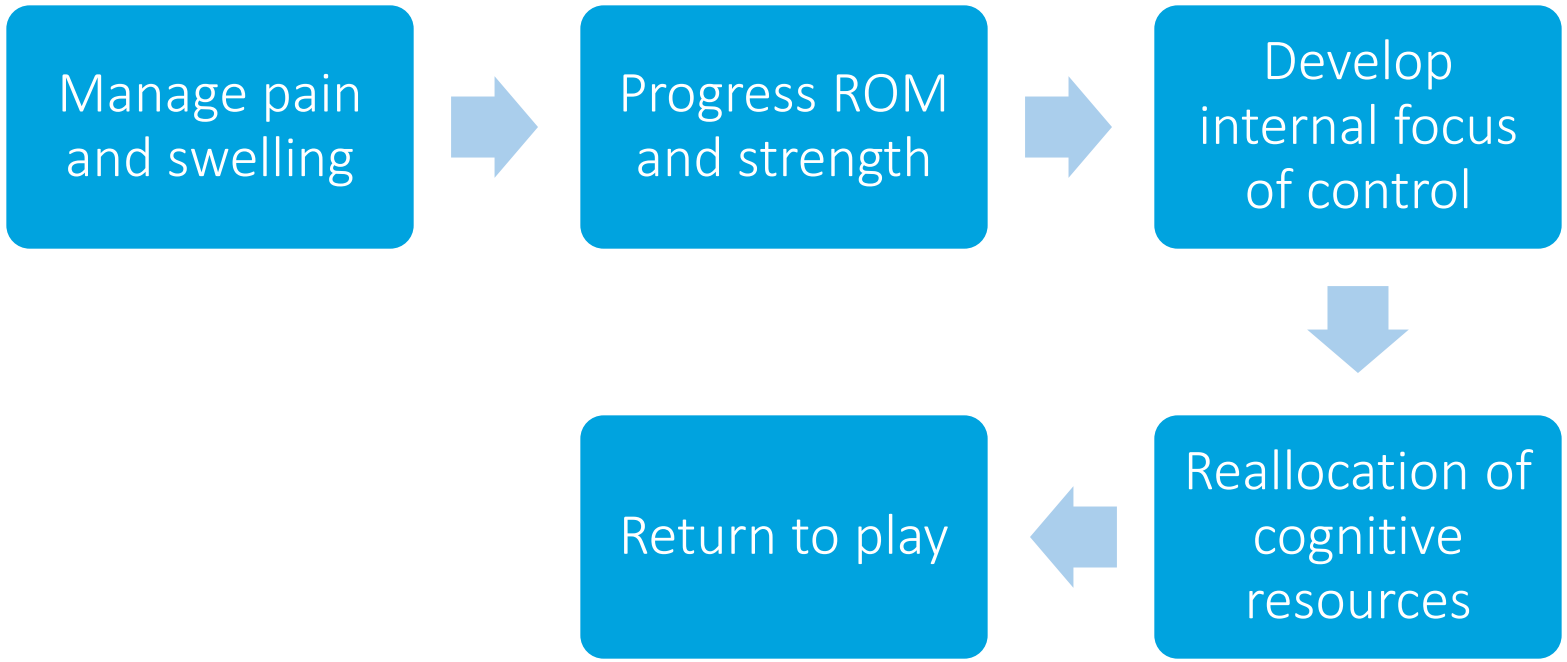
Current practice in post op care



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Neurocognition

- **Who needs to care about Neurocognition?**
  - EVERYONE!

- **What is Neurocognition?**
  - Coordination of mental functions (attention, memory, and decision-making) with sensory input and motor output
  - Vital for effective movement and athletic performance

- **Why incorporate Neurocognition into Practice?**
  - We all use it!
  - Trauma has been shown to modify how the nervous system processes interactions between vision and somatosensory network (Chaput, et al. 2024)
  - **Reduce overutilization** of cognitive resources for simple motor tasks
  - Sports require a level of automaticity without overutilization of cognitive function
  - Promotes performance in increasing chaos

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Neurocognition in Research

- Dr. Meredith Chaput research:
  - How cognitive load can impair movement quality
  - Combining cognitive and motor tasks in rehabilitation to improve attentional resource allocation
  - Promotes a multi-systems approach to rehabilitation (interaction between the nervous, musculoskeletal, endocrine, and cardiovascular systems)
  - The Controlled Chaos Continuum (CCC)
    - Using progressive cognitive-visual dual tasks to reduce cognitive compensation of motor control

Neurocognition in practice

Models of Attention

- **Capacity Sharing Model**
  - Attention is a limited resource that can be shared amongst different tasks
  - Multiple tasks performed simultaneously compete for shared capacity
  - If two tasks require more attention than is available, performance on one or both tasks may suffer

- **The Bottleneck Theory**
  - Certain cognitive processes like decision making and motor planning compete for shared neural pathways
  - Only a limited amount of information can be processed at one time

Promoting Automaticity

- Using the Optimal Theory of Motor Learning supports neurocognition and promotes Motor Automaticity

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Internal Focus of Attention

- The **prefrontal cortex (PFC)** is responsible for executive functions, including conscious control, working memory, and **attention regulation**
- **Internal focus** (“contract your quadriceps”), the PFC becomes more active, engaging in conscious monitoring of movement that was once automatic
- This increased cognitive load can interfere with motor automaticity, leading to slower, less fluid movements.

External focus of attention

- Direct the patient's attention to the **EFFECTS** of the movements on the environment (external focus of attention)
- **External focus** speeds up learning and increases **automaticity**
- Promotes utilization of automatic process and reduces constraints on the motor system
- **External focus** reduces attentional demands
- Reduces instructive learning

External focus instruction to enhance postural stability “Try to keep the bars on the balance board as steady as possible”

Explicit Cueing and Instructions

Explicit:

- Creates internal focus of attention
- Direct the learner's awareness toward body mechanics or specific movements
- Engages conscious control processes—especially in the prefrontal cortex.
- Example: "I want you to squat, bend your knees more, activate you glutes on the way up…"

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Implicit instructions and cueing

- **Implicit instructions** guide attention toward the **effect** of the movement:
  - Example: “push the ground away,” “explode towards the rim,” or “land softly.”
  - These cues encourage an **external focus**, which reduces reliance on the PFC and allows **subcortical motor systems** to dominate.
- **Enhanced Automaticity**
  - With less conscious interference, movements become **more efficient, adaptable, and resilient** under stress.

Task	Explicit instructions	Implicit instructions
Squat	Stand with your feet shoulder-width apart	Stance: Think about keeping a big ball between your knees
	Lower down so your thighs are as parallel to the floor as possible, with your knees over your ankles	Imagine you're picking up a heavy box from the floor
		Imagine you're going to sit down on a chair
Running	Bend your knees while landing	Imagine you run like a feather
		Land softly
		Try to make as little noise as possible
Vertical jump	Bend your knees before you jump Explosively extend hips, knees, and ankles, and propel off balls of feet to jump straight up Landing: bend knees during landing Keep your knees over your toes	Imagine you're landing on eggs and you don't want to crack them Push yourself off the floor as hard as possible Pretend you are a rocket that launches
Countermovement jump	Stand with your feet shoulder width apart Bend your knees before you jump Explosively extend hips, knees, and ankles, and pull your thighs towards your trunk Land with your knees bent	Imagine you're jumping on hot coals and don't want to burn your feet Push yourself off the floor as hard as possible Pretend you are a rocket that launches

Autonomy

- Current: Therapists usually decide the details of the session (task order, duration, etc)
- Autonomy: Give patient some choice in choosing exercise or requesting feedback
- Athletes tend to request feedback after good trials
- Preference towards positive feedback—supports motivational influences on motor learning
- Patients became more involved in the process

Enhanced Expectancies and Neurocognition

- Essentially motivation, confidence and believe of improvement

- The **prefrontal cortex (PFC)** is involved in **self-monitoring**, **error detection**, and **goal-directed behavior**.
  - Enhanced expectancies **reduce overactivation** of the PFC by **lowering self-consciousness and fear of failure**, which can otherwise disrupt automatic motor control.

- Enhanced expectancies allows **motor regions** (e.g., **motor cortex**, **basal ganglia**) to operate more efficiently.

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In Summary

- Optimal Theory of Motor Learning Pillars
  - Autonomy
  - External Focus
  - Enhanced Expectancies

- Utilizing the Optimal Theory of Motor Learning pillars as the foundation of incorporating Neurocognition into your rehab promotes automaticity of movement

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A Motor-Learning Progression Framework

Repetition Loading for Proprioceptive Pathway Retraining

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Movement Is a Brain + Body Problem

Every rep rewires movement to create lasting neural & tissue change

Plasticity is multimodal (sensory, metabolic, emotional, cognitive)

Neurocognitive drills ≠ the whole pie for Neuro Recovery

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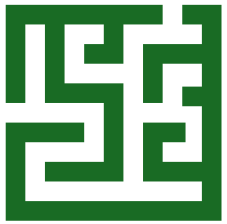
Why High-Repetition or Volume Rehab Matters for Athletes



Neuroplasticity is dose-dependent.

Hundreds-to-thousands of accurate repetitions are required to re-map cortical and spinal circuits after injury.

- A 2021 RCT that paired 60 min of robot-guided reaching with 30 min of conventional therapy

Repetition rate predicts outcome.

In a 2023 home-sensor study, the number of forward reaches per minute explained 83 % of the variance in Fugl-Meyer arm scores

confirming that “how many reps you actually do” drives change, not time on task.

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Why High-Repetition Rehab Matters for Athletes

- **The same principle scales to the lower limb.**
  - A 2024 systematic review of exoskeleton gait programs recommends 60-min sessions, three times per week for nine weeks (≃ 27 sessions) to generate meaningful locomotor gains after spinal-cord injury (SCI).
- **Elite sport already embraces volume.**
  - NBA star Stephen Curry reportedly *makes* 500 shots every day (≃ 3,500/week) to keep his stroke automatic.

Rehab phase	Primary goal	Recommended daily / session volume	Practical tactics
Protection & activation (Days 1-14)	Restore safe ROM, keep neural circuits firing	• Upper limb / trunk: 200-300 assisted or pain-free reps• Lower limb / gait prep: 1 000+ unloaded steps or pedal strokes	▸ Use light bands, isometrics, passive cycling▸ Micro-sessions (5 min blocks, every waking hour)
Motor re-programming (Weeks 2-6)	Overwrite faulty patterns, rebuild endurance	• Target joint skill: 300-600 quality reps• Footwork / gait: 2 000-3 000 steps or 30-40 min stepping• Sport skill drills: 50-100 reps per drill (≥ 300 total)	▸ EMOM* circuits (Every-Minute-On-the-Minute) to keep count▸ Sensor- or robot-assisted devices for high-rep accuracy▸ Gamified AR/VR for motivation
Performance reload (Weeks 6 → return-to-play)	Reinstate speed, variability, fatigue resilience	• Skill-specific reps: 500-1 000+ per week at game speed• Power drills: 40-60 explosive reps / session• Conditioning runs: 3 000-6 000 sport-specific steps	▸ Variable-practice blocks (randomized serves, shots, cuts)▸ Contrast sets (slow-accuracy ↔ fast-power)▸ Integrate into regular team practice to hit volume targets

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Programming Guidelines

BUILD VOLUME WHILE YOU WAIT TO LOAD. EARLY REPS ARE UNLOADED OR ASSISTED; INTENSITY RISES ONLY WHEN THE ATHLETE CAN HIT THE DAILY REP QUOTA WITH FLAWLESS FORM.

DISTRIBUTE PRACTICE. THREE 15-MINUTE BURSTS WITH 100 REPS EACH EVOKE MORE PLASTIC CHANGE THAN ONE 45-MINUTE BLOCK OF 300 FATIGUED REPS.

RESPECT FATIGUE & TISSUE HEALING. MONITOR RPE AND SORENESS; WHEN TECHNIQUE DEGRADES, SWITCH TASKS RATHER THAN “GRINDING” POOR-QUALITY REPS.

PROGRESS WEEKLY BY ~10–15 % IN EITHER TOTAL REPS OR SESSION FREQUENCY UNTIL DEMANDS MATCH PRE-INJURY TRAINING LOADS.

BLEND WITH STRENGTH & CONDITIONING. HIGH-REP MOTOR WORK PAIRS WELL WITH LOW-VOLUME STRENGTH BLOCKS ON THE SAME DAY; AVOID STACKING TWO HIGH-VOLUME STRESSORS BACK-TO-BACK.

GAMIFY FEEDBACK. COMPETITION, IMMEDIATE ACCURACY SCORES, OR SPORT ENVIRONMENT OVERLAYS (SUCCESSFUL IN BASKETBALL FREE-THROW STUDIES) KEEP ENGAGEMENT HIGH.

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Ground Rules for Neuroplastic Reps

SPECIFICITY – REPS MUST MIRROR THE TARGET SKILL

SALIENCE – MEANINGFUL TASKS AND MEANINGFUL CONTEXT

OPTIMAL CHALLENGE – 10–15 % ERROR RATE

DOSAGE – EARLY 300–500 ACCURATE ACTIVATIONS/DAY; MID-LATE 2–3 K ACTIVATIONS/WEEK

SPACING EFFECT – FREQUENT MICRO-SETS > MARATHON SESSIONS

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Neurocognitive Overlays

Early: explicit dual-task during simple exercises

Mid: reactive visual/auditory cues on dynamic drills

Late: implicit constraints (scoring zones, opponent pressure) during high-speed tasks

Must Be Realistic and Meaningful…(Conversational)….

Nervous system does not make correlations well with movement

Power Clean ≠ Vertical Jump and Triple extension ≠ Sprinting

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Levers of Plastic Change

1. Task-specific practice – squat-to-cut progression
   - Work from isolation directly to function.
2. Sensory reprogramming– eyes-closed balance, variable surfaces.
   - Distract the Nervous system
3. Error augmentation – bungees, perturbations.
   - More power in learning to correct errors than never making errors
4. Metabolic & neuro priming – 10-min intense cardio, BFR?
5. Emotional & autonomic arousal – competition, gamification
6. UNPLANNED REACTION!!!–decision movements. Reactive cuts. Movement problem solving.

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Lets Put This Into Action

Post op ACL

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Phase-by-Phase Volume Build-Up (0-2)

Phase 0 – Cortical priming: quad sets 100 reps for speed, max reps in 30 sec.....

Phase 1 – Controlled closed-chain: mini-squat 50 reps, foam pad progression add arm movement, add speed.

Phase 2 – Static single-leg stance: 10 sec holds, add running form, add UE counter weight, add rotation....add speed

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Phase-by-Phase Volume Build-Up (3-5)

Phase 3 – Dynamic balance/low level plyo: 500-1000 contacts/session, 2×/wk;

→

Phase 4 – Multi-planar plyo & agility: 500-1000 contacts/session, 2–3×/wk;

→

Phase 5 – Fatigue (RTS): 3000+ sport contacts/week; unpredictable cues & context. Promote reaction vs any planning.

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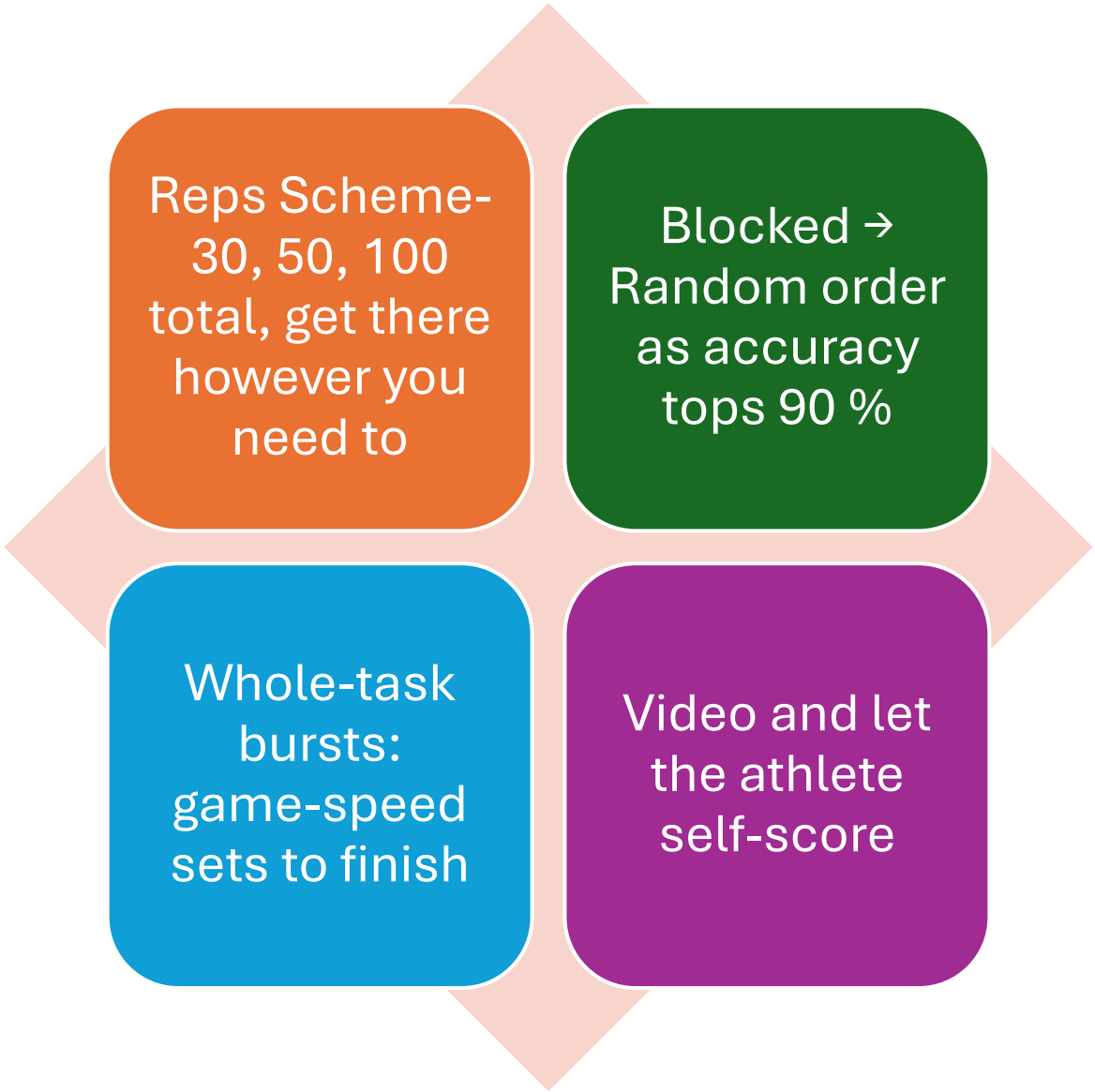
Practice Structure Within a Session



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Progression Guidelines

3 correct reps for biomechanics spot-check

- Then learn from errors and correcting them

Pain ≤ 2/10 during & after task

- Give ability to correct after brief rest
- If Pain affects movement ability alter task

Recovery markers: all must resolve with 24 hrs

- Pain
- Effusion
- Loss of ROM
- Loss of strength

Translating the Evidence Into a Sports-Rehab Playbook

Rehab phase	Primary goal	Recommended daily / session volume	Practical tactics
Protection & activation (days 1-14)	Restore safe ROM, keep neural circuits firing	• Upper limb / trunk: 200-300 assisted or pain-free reps• Lower limb / gait prep: 1 000+ unloaded reps	‣ Use light bands, isometrics, passive cycling‣ Micro-sessions (5 min blocks, every waking hour)
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Don’t Forget Neuro Principles with the Levers

All must be Meaningful and Movement / Sport Specific

Add Volume

Add Load

Add Speed

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From Cortex to Game Day

Start	Layer	Heavy	Measure
Start wide: introduce multiple levers early	Layer, don't swap: keep task practice constant	Periodize Neurocognition: heavy early, taper later	Measure multidimensionally: Isolation to function • Strength • Hops • Movement quality • Power • Speed • Performance

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Putting it all together

Anchor	Blend	Dose	Measure	Educate	Don’t forget
Anchor every drill to a motor-learning lever—ask “Which lever (external focus, variability, error, arousal, NC load) am I pulling today?”	Blend, don’t swap—keep task-specific reps constant while layering or fading other levers.	Dose Neuro Cog early, taper late—heavy dual-tasking in phases 1-3; by phase 4 switch to implicit constraints so automaticity can flourish.	Measure on multiple levels—strength, kinematics, hop symmetry and reaction-time / decision errors and performance for a holistic RTS picture.	Educate the athlete—understanding how brain and body co-adapt boosts engagement and self-monitoring.	Don’t forget Fear - Psychological readiness, Imagery, mental reps.

Why High-Repetition Rehab Matters for Athletes

- **The same principle scales to the lower limb.** A 2024 systematic review of exoskeleton gait programs recommends 60-min sessions, three times per week for nine weeks (≈ 27 sessions) to generate meaningful locomotor gains after spinal-cord injury (SCI).
- **Elite sport already embraces volume.** NBA star Stephen Curry reportedly *makes* 500 shots every day (≈ 3 500/week) to keep his stroke automatic. The rehab world simply has to catch up.

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Motion Lab

Questions

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