Hamstring Injuries: Rehabilitation and Running Enhancement Training

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Robert A. Panariello MS, PT, ATC, CSCS
Founding Partner, Chief Clinical Officer
Professional Physical Therapy
Professional Athletic Performance Center
New York, NY

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Hamstring Injury Presentation Objectives

- The content of this presentation will include:
  - The Running Gait Cycle
  - Sports Rehabilitation and Strength and Conditioning components
  - ACL Reconstructions utilizing hamstring autografts
  - ACL bracing on hamstring activity
  - Hamstring injuries
  - Rehabilitation and performance enhancement training options for hamstring injuries

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Athletic Performance

- Speed is conferred predominately by an enhanced ability to generate and transmit muscular force to the ground." Weyland J Appl Physiol 2000
- The fastest athletes spend the least amount of time on the ground (0.7 – 0.9 sec seconds at sprinting speed
  - ***The main determinant of achieving maximum sprint speed was in reducing the contact time during the stance phase!*** Mann 1998

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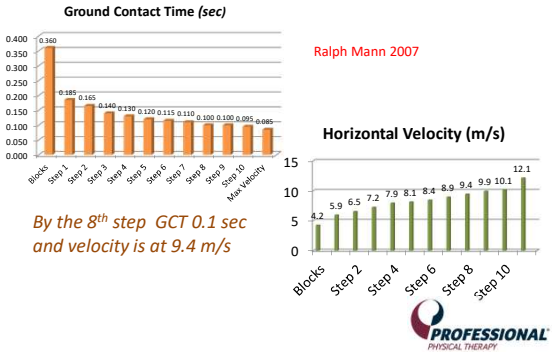
GCT and Horizontal Velocity



Ralph Mann 2007

By the 8th step GCT 0.1 sec and velocity is at 9.4 m/s

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Sir Isaac Newton's Laws of Motion

- The third law of motion states for every action (force) in nature there is an equal and opposite reaction

Sir Isaac Newton (1642-1727)

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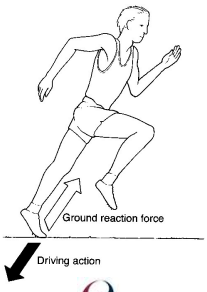
Athletic Performance After ACL and Hamstring Injury

- The athlete needs to reacquire their previous level of physical ability to react to the ground surface area
  - Acceleration
  - Deceleration
  - Change of Direction (COD)



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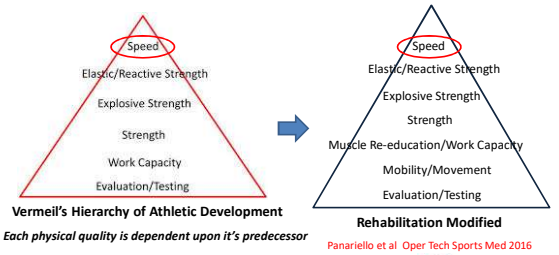
The Hierarchy of Athletic Development

Hall of Fame S&C Coach Al Vermeil's Heirarchy of Athletic Development



Vermeil's Hierarchy of Athletic Development

Each physical quality is dependent upon it's predecessor

Rehabilitation Modified

Panariello et al Oper Tech Sports Med 2016

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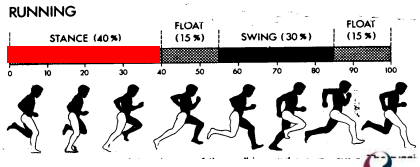
The Running Gait Cycle

- Stance Phase – 40% of the cycle
- Swing Phase – 30% of the cycle
- Float Phase – 30 % of the cycle
- The majority of the Running cycle is spent with the leg off the ground, therefore we must take advantage of the limited time spent on the ground



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The Running Gait Cycle: Stance Phase

- Most important phase of the running cycle
  - Foot and leg bear weight
  - Application of force into the ground surface area
- Traditionally divided into 3 phases
  - Initial Contact
  - Midstance
  - Propulsion

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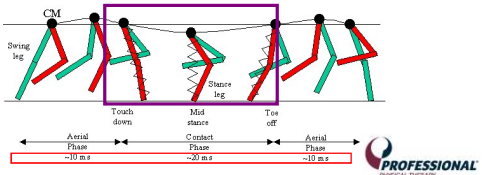
The Running Stance Phase

- Initial Contact
  - When initial contact is made with the ground (heel) and ends when the forefoot makes contact to begin midstance
- Midstance
  - Foot and leg provide a stable support for the body weight to pass over. The opposite extremity is in swing phase
- Propulsion
  - Begins as the heel lifts off the ground to toe off. Ground reaction forces are applied to the ground surface area.



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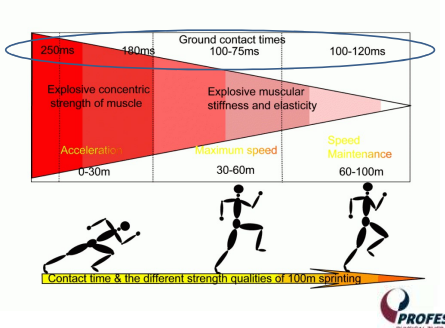
Strength Qualities and the Ground Contact Times During Sprinting



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Anterior Cruciate Ligament (ACL) Injuries

- Approximately 200,000 ACL Reconstructions are performed annually

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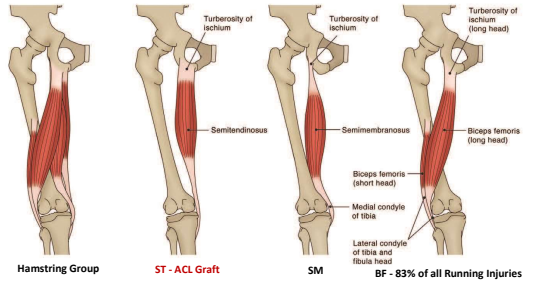
ACL Graft: The Hamstrings



Hamstring Group | ST - ACL Graft | SM | BF - 83% of all Running Injuries

Schuermans et al Br J Sports Med 2014

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ACL Graft: The Hamstrings

14,105 ACL Reconstructions (ACLR)
Kaiser Permanente Baldwin, California

ACL Graft	ACLR Percentage	ACLR Revision (Re-tear) Rate
Hamstrings	5,707 (40.7%)	3.5% (200)
Bone-Tendon-Bone	4557 (32.5%)	2.5% (113)
Allograft	3,751 (26.8%)	3.7% (139)

American Orthopedic Society for Sports Medicine

aossm™ American Orthopaedic Society for Sports Medicine

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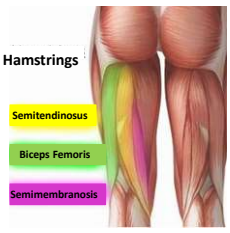
ACL Graft: The Hamstrings

- ACL Grafts
  - Central third patella tendon
  - *Hamstrings*
    - *Semitendinosus tendon*
    - *Gracilis tendon*
  - Quadriceps tendon
  - Allograft
- Hamstrings atrophy and weaken due to:
- The trauma of the initial injury and subsequent ACL surgery
- The initial period of reduced post-op activity
- Limited exercise performance
- Limited high intensity exercise performance
  - Heavy weights
  - Sprinting



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Hamstring Injury: ACL Reconstruction

- Hamstring graft
  - Semimembranosus
  - Gracilis
- Decreased hamstring strength due to:
  - Harvest of the hamstring graft
  - Post-op inactivity
    - Low exercise intensity
    - Lack of high intensity exercise i.e. sprinting

Semitendinosus and Gracilis ACL Graft

Hamstring Graft: ACL Bracing

- Fairly rigid cylindrical brace
- Applied over muscle and fatty tissue
- No control of hip motion
- Allows 8 – 9 degrees of valgus/varus
- Allows 5 – 6 degrees of internal rotation

ACL Bracing

- Neural Effect
  - Torn ACL results in lost afferent and efferent (proprioception) sensors
- Bracing
  - Provides extra-articular tactile sense
  - Establishes parallel “control circuits” for tactile sense

ACL Bracing: Knee Sleeve

- Neural Effect
  - Torn ACL results in lost afferent and efferent (proprioception) sensors
- Knee Sleeve
  - Easier and cheaper
  - Provides extra-articular tactile sense
  - Establishes parallel "control circuits" for tactile sense

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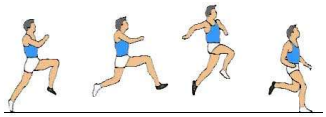
ACL Bracing

	Single Leg Jump	Muscle Activity		
Phase	**Time Interval**	**ST**	**BF**	**RF**
A1	250 ms Preceding Foot Strike (Anticipation of foot strike)	Decreased 17%		
A2	125ms Following Foot Strike (Peak Force Attained)		Decreased 44%	Increased 21%

Ramsey et al Clinc Biomech 2003

- ST – Semitendinosus
- BF – Biceps Femoris
- RF – Rectus Femoris



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ACL Bracing and Knee Sleeve

- Neuro motor standpoint
  - Are we creating a "crutch" for the patient?
- Tightening of the sleeve straps
  - Altering muscle activation
  - Reduced hamstring
    - Muscle fiber recruitment
    - Activity

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Hamstring Injuries

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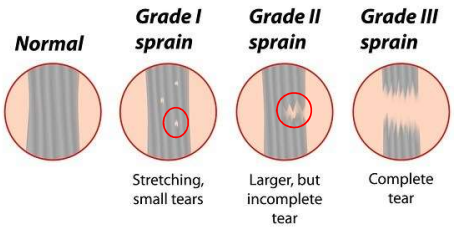
Hamstring Injuries



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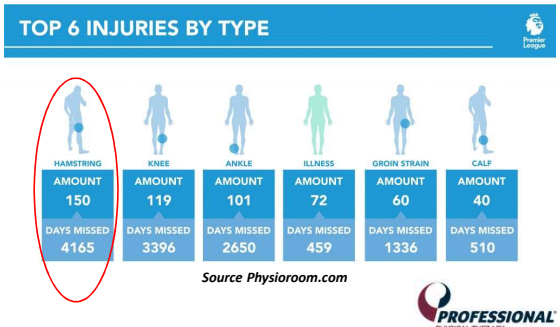
Hamstring Injuries: 2016 – 2017 Premier League Soccer Season



Source Physioroom.com

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Hamstring injuries

- Injury rate of 12% - 16% of all injuries to athletes
- Most common injury in male soccer players Ekstrand et al AJSM 2011 Elliott et al AJSM 2011 Verrall et al J Sci Med Sport 2006
- Re-injury rate reported as high as 22% - 34% Marcus et al AJSM 2011

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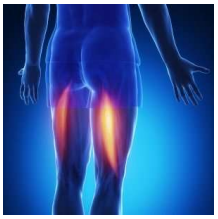
Hamstring Injuries

- Modifiable and Non-modifiable risk factors
- *Modifiable*
  - Rotated innominate
  - Hamstring weakness Orchard et al AJSM 1997
  - Poor flexibility Fousekis et al Br J Sports Med 2011
  - Poor warm-up Worrell Sports Med 1994
  - Muscular fatigue Small et al Int J Sports Med 2009
  - Poor core stability Sherry JOSPT 2004
  - Poor lumbar posture Hagglund et al Br J Sports Med 2006
- *Non-modifiable*
  - Age
  - Ethnicity
  - History of a previous hamstring injury*
    - *Most consistent risk factor
    - Increase risk reoccurrence 2 – 6 times

Engebretsen Am J Sports Med 2010



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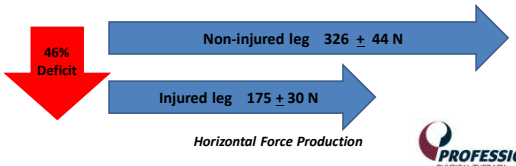
Hamstring Injuries

- Australian rules football players
- At least 1 acute hamstring injury in previous 2 years
- Running at 80% max velocity (Vmax)
- Deficits found in horizontal force

Brughelli M et al J Strength Cond Res 2010



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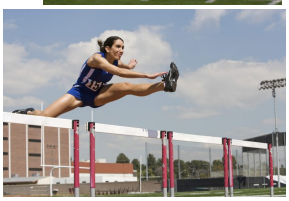
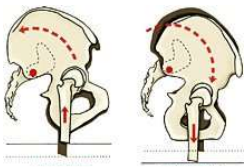
Rotated Innominate

- Rotated Anterior
- Rotated Posterior

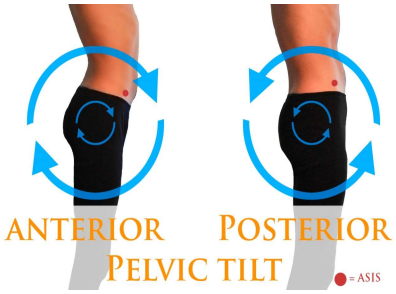


Clinical Pearl: Rotated Innominate

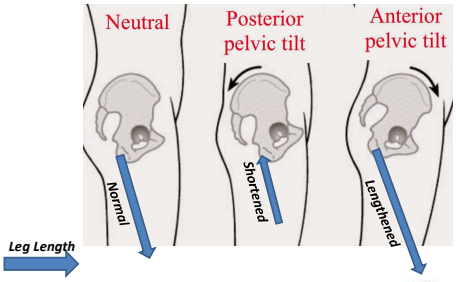
- There is a normal rotation of each innominate (pelvis) during gait (walking) and sprinting
- When an innominate becomes "stuck", and is unable to come out of this position, this limited pattern of movement may become a contributory mechanism for hamstring injury



Hamstring Injury: Rotated Innominate



Rotated Innominate: Anterior or Posterior Pelvic Tilt

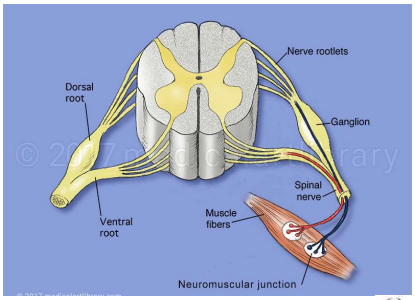


Hamstrings: Mechanism of Injury

- Terminal swing phase of sprinting Schache et al Med Sci Sports Exer 2012
  - Eccentric contraction of lower limb
  - Absorb kinetic energy and slow the lower limb
- Early stance phase of sprinting
  - Muscles absorb high ground reaction forces
  - Higher forces in the concentric stance phase

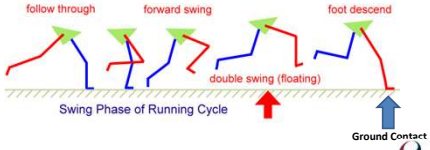
Komi J Biomechanics 1990

Hamstring Injuries: Neuromuscular Factors



Hamstring Injuries: Neuromuscular Factors

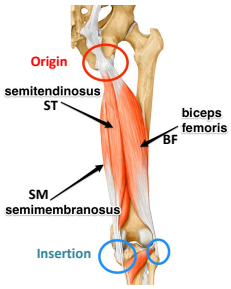
- Maximum length of hamstring muscles noted at late swing phase of sprinting
- Biceps Femoris (BF) - Peak musculotendon length is synchronous with peak EMG activation
- Semitendinosus (ST) Muscle - Peak musculotendon length occurs significantly later than peak level EMG activation
- *These results suggest that the BF muscle is exposed to an instantaneous high tensile force during the late swing phase of sprinting, indicating a higher risk of muscle strain injury* Higashihara et al Eur J sport Sci 2016



Hamstring Injuries – Neuromuscular Factors

- Hamstring muscle activation occurring at different running speeds of maximum velocity
- Running speed of 85% to 95% max velocity
  - Increased activation of hamstring muscles during late swing
  - No change in lower extremity kinematics
- 95% max running velocity
  - Significant different peak muscle activation time in BF vs. ST
  - P <0.05 stance phase
  - P<0.01 swing phase
- *Complex neuromuscular coordination patterns occur at maximal running velocities*

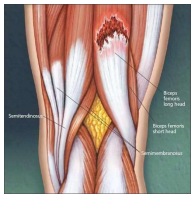
Higashihara et al J Sport Sci 2010



Hamstring Injuries: Neuromuscular Factors

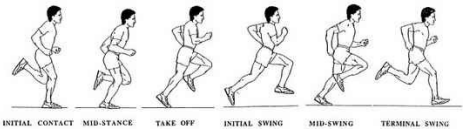
- ST and BF engage in maximal eccentric activation throughout the swing phase
- These synergists work alternatingly (asymmetrical) in complex neuromuscular coordination
- Biceps Femoris
  - Predominate activity is middle to late swing
- Semitendinosus
  - Predominate activity is terminal swing
- Injured Hamstrings
    - More symmetrical muscle recruitment pattern
    - Compensatory recruitment pattern
  - Less economic hamstring activation
  - Lower strength endurance capacity
  - May increase the risk of re-injury

Schuermans et al Br J sports Med 2014



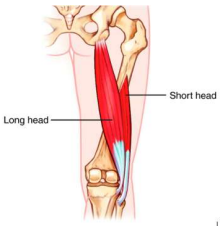
Hamstring Activation: Acceleration vs. Maximum Speed Phases

- Early stance acceleration phase
  - Hip extension torque is greater vs. max speed
  - EMG of BF (long head) greater than ST muscle
- Late stance and terminal mid-swing of max speed
  - Higher knee flexor moment and with greater extension vs. acceleration phase
  - EMG of ST great than BF long head
- Functional demands of medial and lateral hamstring differ at different phases of sprinting Higashihara et al J Sports Sci 2018



Hamstring Injuries: Neuromuscular Factors

- Biceps Femoris
  - Dual nerve innervation
  - Long head
    - Tibial branch of sciatic nerve
  - Short head
    - Common peroneal (fibular) branch of sciatic nerve



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Hamstring Neuromuscular Factors After ACL Reconstruction

- Hamstring activation and strength are important for:
  - Maintenance of appropriate tibiofemoral alignment
  - Prevention of excessive anterior tibial translation
- Athletes 1 – 6 years post ACLR have inter-limb activation differences in hamstring firing time compared to a healthy control cohort

Breim et al Knee Surg, Sports Trauma, Arthroscopy 2016

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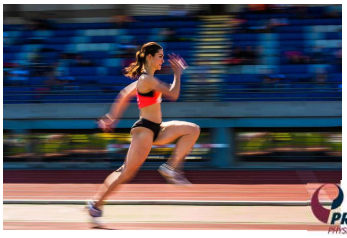
Restoration of Hamstring Neuromuscular Contributions

- Optimal restoration of the physical qualities
- Restoration of neuromuscular control and timing
- Progressive training program of sprinting velocities

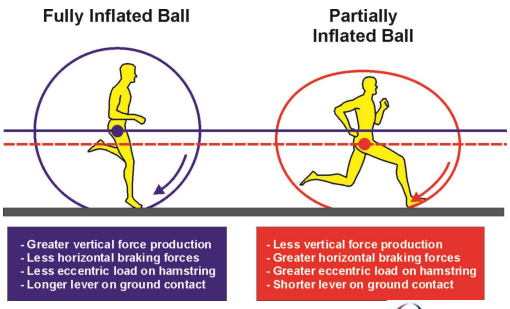


Hamstring Injuries: The Physical Quality of Strength

- *Strength*
  - CORE
  - Hip musculature
  - Lower extremity musculature

Vermeil's Hierarchy of Athletic Development

CORE: Influence of Gravity and Elasticity



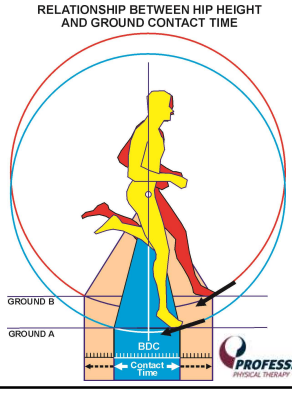
Courtesy Derek Hansen

Hip Height and Ground Contact Time

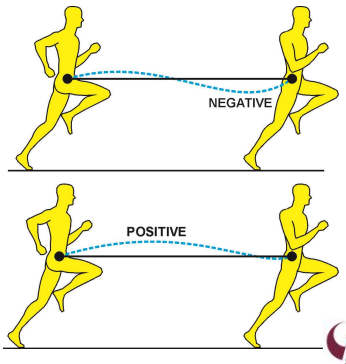
Proper Vertical hip height

- Increases both flight time and a greater distance covered due to the "toe off" occurring closer to the body's center of mass
- Reduces ground contact time (amortization) resulting in an optimal Stretch Shortening Cycle (SSC)

Courtesy Derek Hansen



Positive and Negative Vertical Displacement

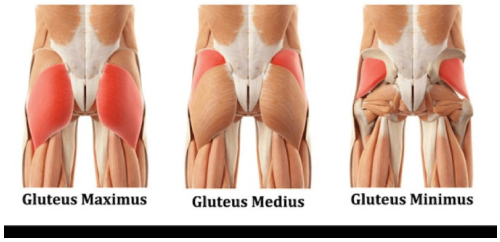


Courtesy of Derek Hansen

CORE Exercise

Hip (Gluteal) Strength

- Propulsion
- Deceleration
- Change of Direction (COD)



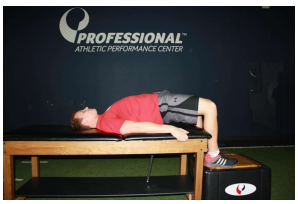
Testing for Gluteal Strength

Positioned for Hamstring Active Insufficiency

Active Insufficiency of a Muscle

- Active Insufficiency occurs when a multi-joint muscle reaches a length (shortened) where it can no longer apply an effective force

Testing for Gluteal Strength



Bi-lateral Leg Bridge

Single Leg Bridge

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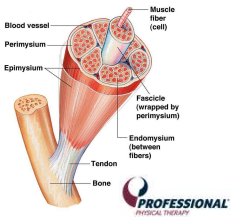
Hamstring Injury

- Tearing of soft tissue
  - Grade I, II, or III
  - ST Hamstring ACL graft
- Healing occurs via muscle scaring
  - Shortening of the muscle fascicles
  - 10 to 100 muscle fibers in a fascicle

Normal Muscle Tissue | Scar Tissue in muscle after injury



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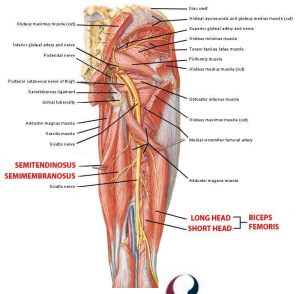
Hamstring Injury: Nerve Entrapment

- Sciatic Nerve
  - Scar formation may "restrict" the sciatic nerve



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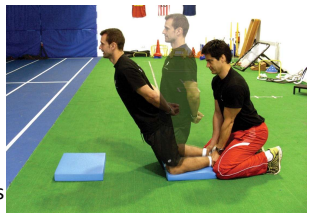
Hamstring Injury: Nerve Glides

Hamstring Force Production

- Peak hamstring torque occurs at significantly shorter muscle lengths in injured hamstrings Brockett el al Med Sci Sports Exerc 2004
- Potential weakness at longer (previous) muscle lengths
- Eccentric training in the lengthened state may shift the torque curve at the end ROM Schmitt et al int J Sports Phys Ther 2012

Hamstring Injury: Strength Training

- Strengthen muscle fibers
- Strengthen at a lengthened muscle fascicles/fiber position
  - Terminal knee/hamstring muscle lengths
- Romanian Deadlift (RDL's)
- Nordic hamstring exercises



Nordic hamstring exercise does not achieve terminal length strengthening

Hamstring Strengthening: Terminal Knee Extension

Hamstring Strengthening: Terminal Knee Extension

- Romanian Deadlift (RDL)

Hamstring Strengthening: Terminal Knee Extension

Romanian Deadlift (RDL)

Ground Contact

Hamstring Strengthening: Kettlebell Swings

Swing Type	Portion of ROM	Medial Hamstring % EMG	Biceps Femoris % EMG	MH vs. BF % EMG
Hip Hinge	Concentric	44.89 ± 25.02	32.65 ± 14.47	12.24 ± 10.55
	Eccentric	28.80 ± 16.36	21.51 ± 15.04	7.29 ± 1.32

Del Monte et al J Strength Cond Res 2018

Hip Hinge Kettlebell Swing

- Medial Hamstrings are used as an ACL graft
- May be initiated early in the rehab process
- MH strength and power
- Initiate deceleration abilities
  - Eccentric muscle contraction

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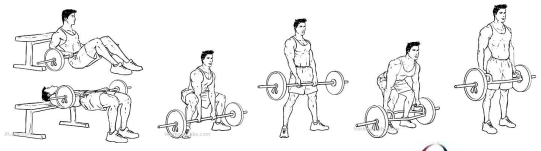
Gluteus Maximus and Hamstring Strength Development

Concentric Phase of the Exercise Performance

Exercise	Gluteus Maximus	Biceps Femoris	Erector Spinae
Hip Thrust	1	3	No
Barbell Deadlift	3	1	Significant
Hex Bar Deadlift	2	2	Difference

Andersen et al J Strength Cond Res 2018



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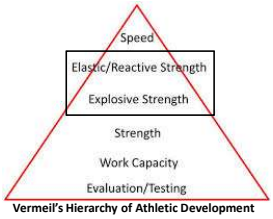
Hamstring Injury: The Physical Qualities of Explosive and Elastic/Reactive Strength

- Explosive Strength
  - Olympic Lifts
    - Pulls
  - Maximal effort jumps
  - Medicine ball tempo
- Elastic/Reactive Strength
  - Plyometrics
    - i.e. Multiple jumps and hops
  - Sprinting
    - Purest form of plyometric training



Vermeil's Hierarchy of Athletic Development

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Elastic/Reactive Qualities of Sprinting

- 4.6 Second 40 Yard Dash
- Sprinting Velocity of approximately 9-10 m/s
- Initial speeds up to 7 m/s requires more "strength" qualities
- Speed exceeding 7 m/s requires "elastic strength" qualities Cavagna J Physio 1971

Sprinting Velocity 7 m/s > 7 m/s

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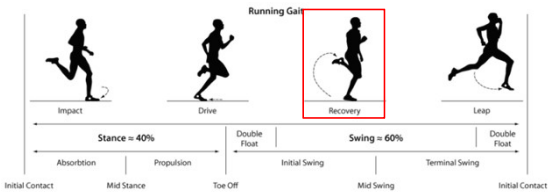
The Physical Quality of Speed

- Re-establish Velocity Training
  - Linear velocity
  - Neuromuscular Timing
  - Sprinting patterns
    - Swing Phase
      - ***Active*** hip and knee ROM
      - Heel position at gluteal fold
    - Float Phase
      - Neither foot in contact with the ground surface area
    - Stance Phase
      - Initial ground contact
      - Eccentric to concentric

Vermeil's Hierarchy of Athletic Development

Restoring Active Knee Range of Motion (AROM)



The Running Gait Cycle

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Knee AROM - The Swing Phase

- Moment arms (distance) of heel to butt

Figure 1

Figure 2

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The Running Gait Cycle

The Running Gait Cycle is just that, a "Cycle". If you negatively affect one phase of the cycle, you negatively affect the entire cycle.

Poor Stance Phase
Poor Swing Phase
Poor Left Lower Extremity
Poor Right Lower Extremity

= **Poor Running Cycle**

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Velocity Training - Modified Running Progressions and Mach Drills

- "A", "B", and "C" running drill series developed by track & field coach Gerard Mach
- Clinical Progression
  - "A" walks/marches
  - "A" skips low
  - "A" skips (high)
  - "A" runs
- Running
  - 10 yard sprints

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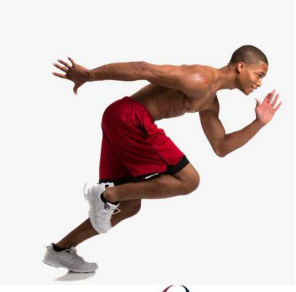
Velocity Progressions

Modified Mach Drills

Poor Strength Qualities	Fair/Good Strength Qualities	Good/Excellent Strength Qualities
Marching/Walking "A"'s	"A" Skips partial/full ROM	Running A's perfect technique
Mirror Drills	Running "A"'s partial/full ROM	Bounding
Seated arm action activities		Sprinting

Hamstring: Velocity Progressions

- Velocity Progression
  - Modified Mach Drills
  - Mach Drills
    - "A" Series
  - 10 Yard Sprints



"A" Marches/Walks

- Simple means of controlling running limb mechanics in a slow disciplined fashion
- Fascicle length and proper alignment of scar tissue
- A rehearsal of the vertical qualities of stepping from stride to stride
- Coordinate arm movements to match the front side characteristics of the legs
- Teaches swing leg to a maximum height to the level of the hip
- Instills foot decent in a vertical movement pattern (vs. horizontal) with ground placement a few inches anterior to the support leg
- Vertical limb patterns assist in teaching the prevention of over striding
- The exercise should initially be performed walking heel to (rehabilitation) and progressed onto the balls of the feet with the heels slightly off the ground

Fascicle Length and Scar Tissue Alignment

CPM Machine

"A" Walks "A" Skips

"A" Marches/Walks

Low "A" Skips and "A" Skips

- Bridges the gap from "A" Marches/Walks to "A" Runs
- Low "A" Skips are a rehabilitation progression
- Performed with the same posture and limb paths as "A" Marches/Walks
- Adds limb velocity, vertical force production, and elastic components vs. the "A" March/Walk exercise
- Acceleration of the foot downward to the ground evokes:
  - Stretch reflexes of the foot and lower leg
  - Vertical displacement of the body
- Perform light and quick foot contacts

Low "A" Skips

"A" Skips

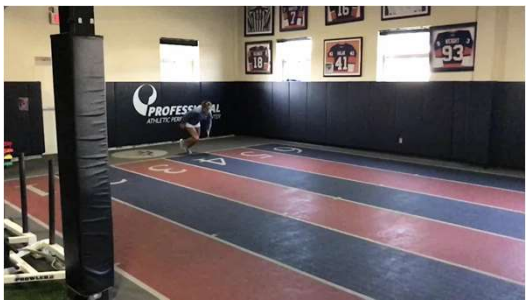
"A" Runs

- Cyclical stimulation of actual sprinting
- Preparation for stride frequency and vertical force production
- "Step over" cueing (are related to stance limb) progression:
  - Ankle
  - Calf
  - Knee
- Goal is 30 strides over 10 yards
  - Metabolic requirements of sprinters

"A" Runs

Resisted "A" Runs

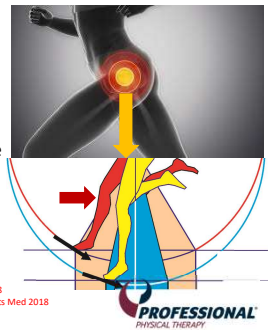
10 Yard Sprints



10 Yard Sprint

Clinical Pearl: Sprinting Volumes

- Sprint Acceleration in a *fatigued environment:*
- Decrease in:
  - Maximal power
  - Horizontal force production
    - Hips and center of mass drops
    - Increased braking forces
- Decrease in concentric peak torque during swing and terminal swing phases:
  - Knee flexors
  - Gluteal maximus
  - Vastus lateralis
- Increased Swing and GC times



Edouard et al Frontiers 2018
Evans et al J Phys Ther Sports Med 2018

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ACL Hamstring Graft/Hamstring Injury: Return to Play

Vermeil's Hierarchy of Athletic Development

A need for a sprinting progression and the need to maintain maximal velocity sprint training ⇒ re-establish/maintain neuromuscular timing

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RPanariello@Professionalpt.com

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