Standardized Clinical Video Analysis of the Injured Runner

Bryan Heiderscheit, PT, PhD
Professor
Department of Orthopedics and Rehabilitation
Department of Biomedical Engineering
Director, UW Runners' Clinic
Director, Badger Athletic Performance Research
Co-director, UW Neuromuscular Biomechanics Lab

UW Neuromuscular Biomechanics Lab

UNIVERSITY OF WISCONSIN BADGER ATHLETIC PERFORMANCE

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Disclosure

I have no relevant financial relationships to disclose

Examination Components

History and Physical Examination
- understand training habits
- consider running-related goals
- identify physical impairments

↓

Running Gait Analysis with Video
- characterize running mechanics
- determine landing posture
- develop tissue loading profile

↓

Footwear Assessment (and Orthoses)
- classify level of support
- determine appropriateness of fit
- identify evidence of breakdown

Intake Form

- Facilitate history taking
- Describe training factors
- Define running-related goals

UW SPORTS MEDICINE
RUNNERS' CLINIC

UW Health
University of Wisconsin
Sports Medicine

Name: ____________________ Email: ____________________

BACKGROUND

What brings you here? ____________________

When did the current problem begin? ____________________

How did it happen? ____________________

Do you have pain *while* running? ☐ Yes ☐ No If so, what happens to the pain while running? ☐ increases ☐ decreases

Do you have pain *after* running? ☐ Yes ☐ No If so, how long does it last? ☐ < 1hr ☐ 1-2 hrs ☐ 2-6hrs ☐ 6+hrs

Does anything alleviate the problem? ☐ medication ☐ rest ☐ stretching ☐ heat/cold ☐ other: __________

Past injuries:	Right	Left	running related		Right	Left	running related
Low back pain	☐	☐	☐	Compartment syndrome	☐	☐	☐
Iliotibial band syndrome	☐	☐	☐	Achilles tendonitis	☐	☐	☐
Knee pain	☐	☐	☐	Plantar fasciitis	☐	☐	☐
Stress fracture	☐	☐	☐	Other	☐	☐	☐
Shin splints	☐	☐	☐				

Current medications: ☐ aspirin ☐ Advil/motrin/ibuprofen ☐ Tylenol ☐ bronchodilators
☐ vitamin D ☐ calcium ☐ others: __________

TRAINING

Years running: ________ How would you classify your level of running? ☐ recreational ☐ competitive

Volume: ______ miles/week ______ days/week ______ months/year Pace: ________ min/mile

Speed work: ☐ Yes ☐ No Hill Repeats: ☐ Yes ☐ No Warm-up: ☐ Yes ☐ No Cool-down: ☐ Yes ☐ No

Stretching: ☐ before run ☐ after run ☐ throughout day

Typical racing distance: ☐ 5-10K ☐ ½ marathon ☐ marathon ☐ ultradistance ☐ triathlon ☐ other__________

What foot-strike pattern do you use? ☐ rearfoot ☐ midfoot ☐ forefoot ☐ uncertain

FOOTWEAR

Shoe brand/model: __________ Shoe age: ______ months Are your shoes comfortable? ☐ Yes ☐ No

Orthotic/Insert ☐ Yes ☐ No If yes: ☐ custom ☐ over the counter Heel lift: ☐ right ☐ left ☐ none

RUNNING MOTIVATION AND GOALS

What is the primary reason you run? ☐ general fitness ☐ weight control ☐ stress control ☐ social reasons ☐ competition

What are your running goals? [check all that apply]

☐ continue running at current level ☐ increase running to higher level

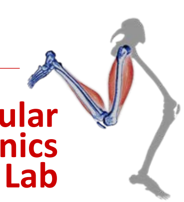
☐ compete in specific race: distance__________ date__________

☐ other: ____________________

v10.29.2013 © Heiderscheit

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab



Running-Specific Outcome Tool

- Develop a running specific tool for assessing improvement following an injury that is valid, reliable, and sensitive to change for use in clinical practice and research

  - Condition specific tools (e.g., Kujala, Visa-A)
    - Limited assessment of return to sport
    - Limits research with diverse injuries

  - Body region specific tools (e.g., LEFS, FAOS)
    - Demonstrate significant ceiling effect
    - Too specific to a single region

University of Wisconsin Running Injury and Recovery Index (UWRI)

Development Process

1. Interview injured runners of all performance levels
2. 42 questions indentified as factors relating to the running injury
3. Importance product: Assess question importance and relevance
4. 9 key questions identified and included in UWRI
5. Question clarification process with UWRI

UWRI

- University of Wisconsin Running Injury and Recovery Index
- Perfect score = 36
- Good psychometric properties:
  - test-retest reliability
  - Internal consistency
- MCID in progress

University of Wisconsin Running Injury and Recovery Index (UWRI)

Instructions: Consider your current running injury over the past 7 days when answering each question. Check (☒) the appropriate box.

1. How does your running injury impact your ability to perform daily activities?	☐ No impact	☐ Slightly impact	☐ Moderately impact	☐ Significantly impact	☐ Unable to perform
2. How frustrated are you by your running injury?	☐ Not frustrated	☐ Mildly frustrated	☐ Moderately frustrated	☐ Significantly frustrated	☐ Extremely frustrated
3. How much recovery have you made from your running injury?	☐ Complete recovery	☐ Significant recovery	☐ Moderate recovery	☐ Minimal recovery	☐ No recovery
4. How much pain do you experience while running?	☐ No pain	☐ Minimal pain	☐ Moderate pain	☐ Significant pain	☐ Unable to run
5. How much pain do you experience during the 24 hours following a run?	☐ No pain	☐ Minimal pain	☐ Moderate pain	☐ Significant pain	☐ Unable to run
6. How has your weekly mileage or weekly running time changed as a result of your injury?	☐ Same or greater than before my injury	☐ Minimally reduced	☐ Moderately reduced	☐ Significantly reduced	☐ Unable to run
7. How has the distance of your longest weekly run changed as a result of your injury?	☐ Same or longer than before my injury	☐ Minimally reduced	☐ Moderately reduced	☐ Significantly reduced	☐ Unable to run
8. How has your running pace or speed changed as a result of your injury?	☐ Same or faster than before my injury	☐ Minimally reduced	☐ Moderately reduced	☐ Significantly reduced	☐ Unable to run
9. How does your injury affect your confidence to increase the duration or intensity of your running?	☐ Confident to increase my running	☐ If I increase I might be fine	☐ Neutral	☐ If I increase I might get worse	☐ I cannot increase my running

OFFICE USE ONLY

SCORE

Scoring Key:	4	3	2	1	0

v12.11.2012 © Heiderscheit

Page 2 of 3

Nelson (2013) J Orthop Sports Phys Ther (abstract)

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

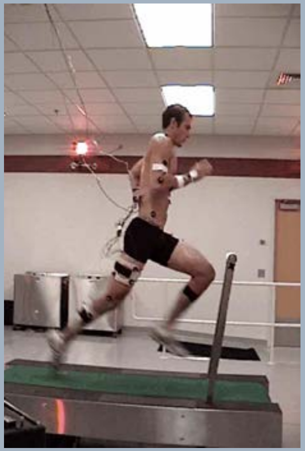
UW Neuromuscular Biomechanics Lab

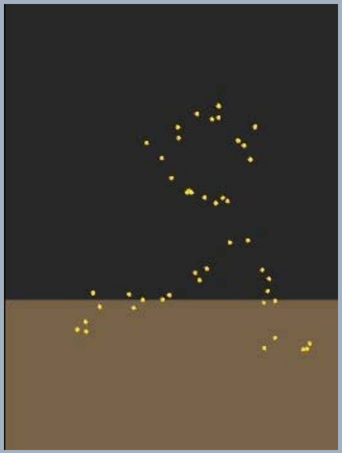
Physical Examination

- Goals:
  - Determine injury diagnosis/severity in combination with history
    - Identify involved tissues
  - Identify physical impairments and characterize musculoskeletal status
    - Consider all aspects relevant to running
    - Necessary to determine if running mechanics are an appropriate match

Motion Analysis Options

3D
Lab





2D
Camera

Reliability

- Orthopedic walking gait assessment
  - moderate inter-examiner reliability
  - good intra-examiner reliability
  - increased reliability with increased experience

Brunnekreef (2005) *BMC Musculoskeletal Dis*

- Rearfoot motion during walking
  - poor inter-observer
  - poor-fair intra-observer

Keenan and Bach (1996) *Arch Phys Med Rehab*

- improve reliability
  - systematic approach
  - likert-scale measures
  - experience

Kotecki et al. (2013) *J Orthop Sports Phys Ther*

Assessing Running Mechanics

- 3 common questions:
  1. overground or treadmill?
  2. what type of camera?
  3. what type of video software?

Treadmill or Not

	Overground	Treadmill
Ecological validity	Yes	No
Control Speed	No*	Yes
Fixed relationship between camera and runner	No*	Yes

*requires additional equipment

Are Mechanics Different on Treadmill?

- Step length is commonly reduced when running on a treadmill
- Running form normalizes within 6 min of treadmill running

Lavcanska et al. (2005) Hum Mov Sci

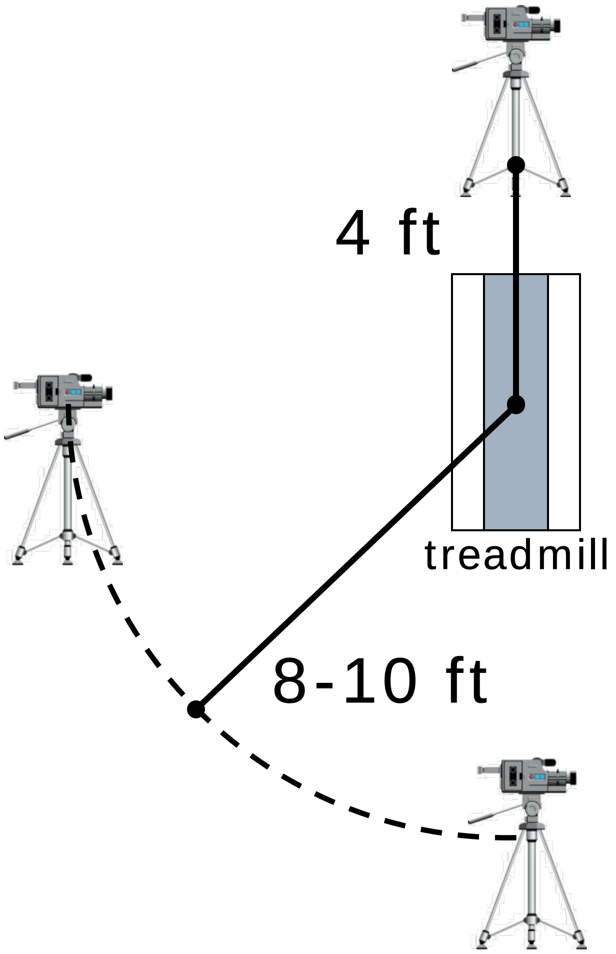
<u>Treadmill Specifications</u>

1. Stiff running deck
   - If too compliant, runner will adjust mechanics (e.g., increase lower extremity stiffness)
2. Regulated belt speed
   - If motor is underpowered, then the belt speed decreases at foot-ground contact

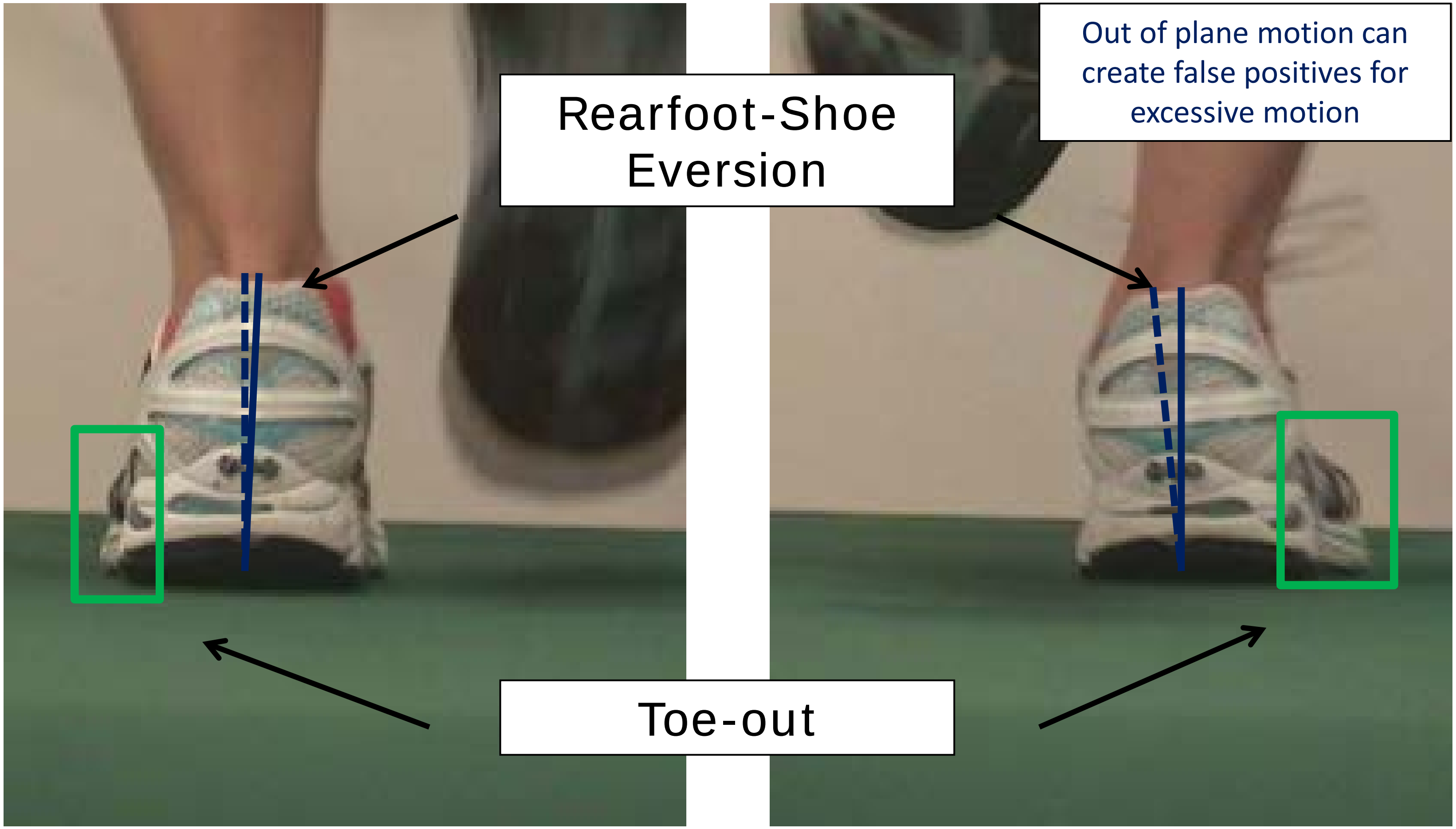
Riley et al. (2008) Med Sci Sports Exerc

Equipment Set-up

- Cameras must be placed perpendicular to the plane of interest
  - Frontal plane is most sensitive
  - Transverse plane is inferred
- Adequate space for video capture from multiple angles
  - Able to view whole body from side and back



Out of Plane Motion



What Camera?

<u>Sampling rate</u> (frames per second, fps)

- Influences the number of pictures you have to determine movement
  - Human eye ~16 samples/s
  - Video camera – 30-60 samples/s
  - Digital camera ≤ 1000 samples/s

- Observation alone is insufficient to capture body posture at specific events of the gait cycle

Maximum Pronation

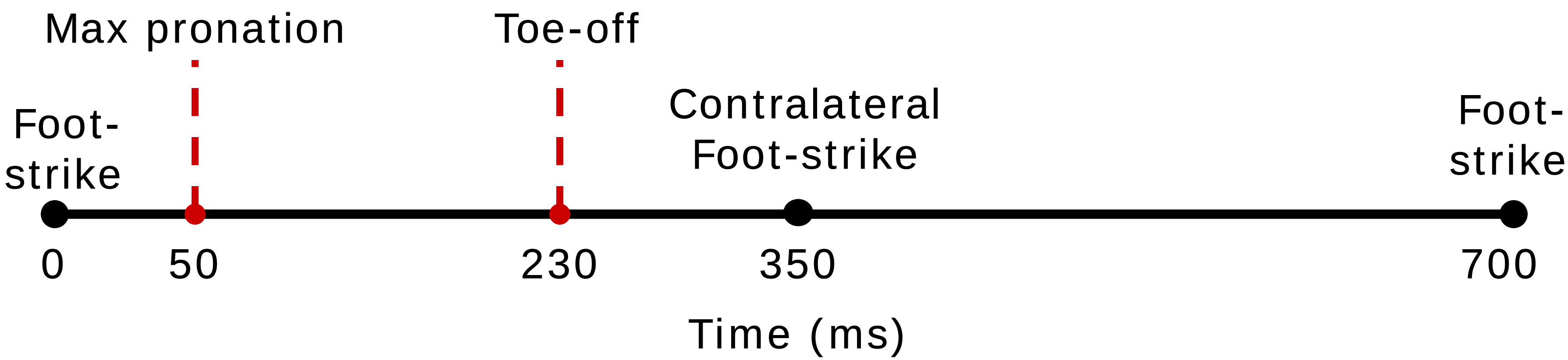
Barefoot walking

Shod running

Shod running with custom orthotics

Timing of Events

- Running speed of 3.83 m/s (8.57 mph or 7 min/mile)

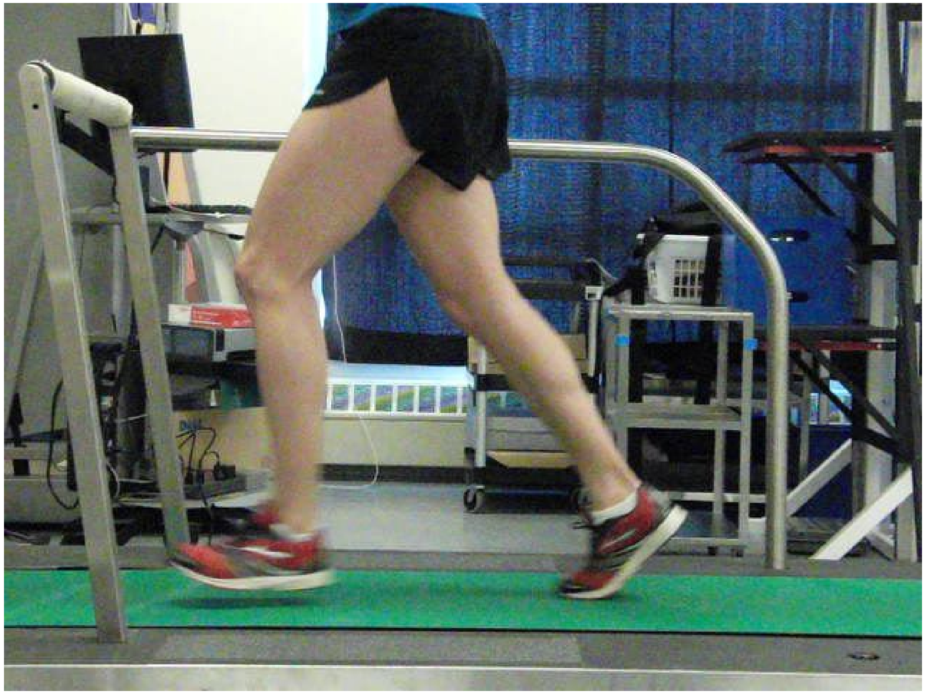


- Time interval between samples:
  - Eye = 62.5 ms
  - Video camera (30 fps) = 33.3 ms
  - Video camera (60 fps) = 16.7 ms
  - High speed camera (100+ fps) = < 10 ms

High Speed Cameras

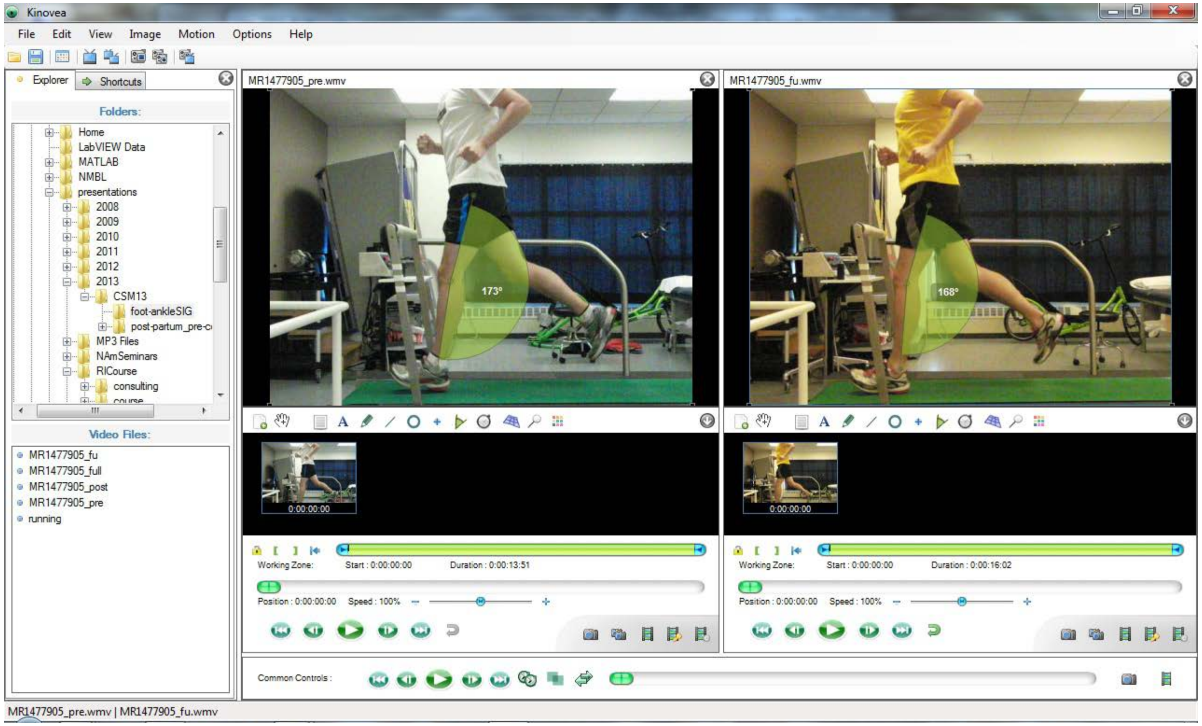
2000 fps

120 fps



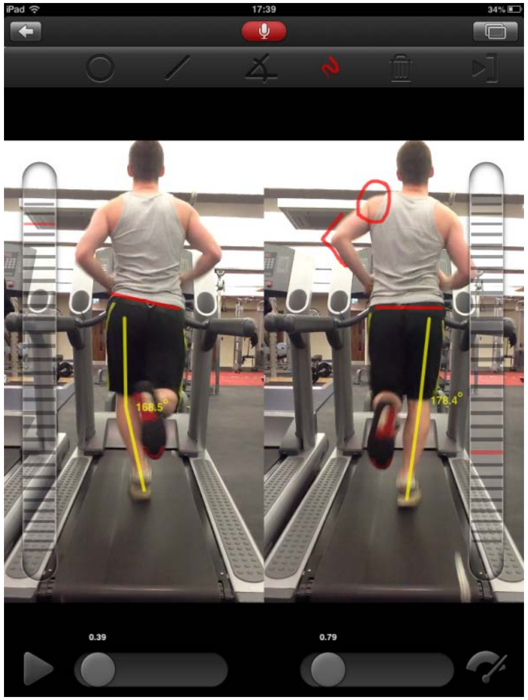
What about Video Software?

- Benefits
  - Potential to display 2 videos synchronously
  - Patient education
  - Database structure
- Does not increase accuracy
  - Still a 2D image



Phone and Tablet Options

- iPhone 6 records:
  - 60 fps at 1080p
  - 120/240 fps at 720p
- iPad Air 2 (not mini)
  - 120 fps at 720p
- Limitations
  - digital zoom
- Many video analysis Apps
  - UberSense
  - CoachMyVideo
  - iCoachView



EMR Considerations

- Video storage is rarely a basic feature of electronic medical record systems
  - Potential need for a custom-build
- Upload of report as PDF is feasible, but limits ability to search information when compiling data
- At minimum, need to ensure the interpretation of the video is included in examination for billing purposes

Joint Interaction

Lumbar Side Bend and Rotation

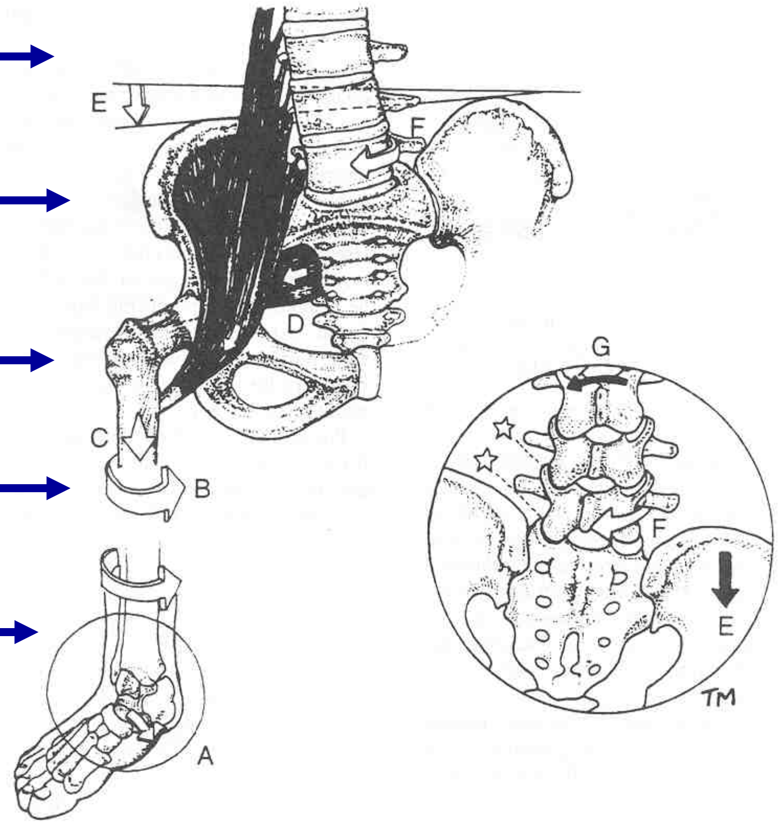
Pelvic Lateral Tilt

Femoral Internal Rotation

Knee Medial Collapse

Tibial Internal Rotation

Foot Pronation



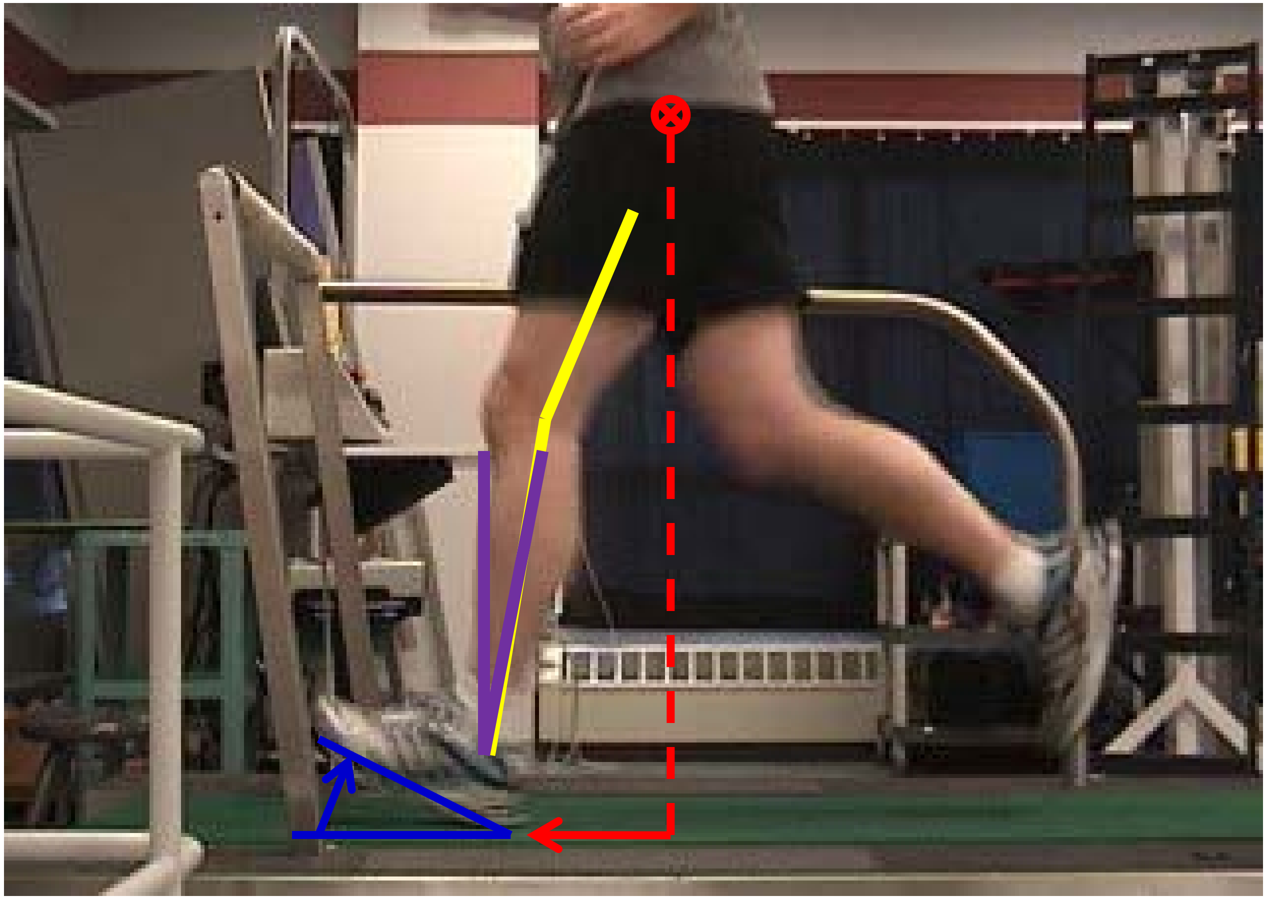
From Hammer (1999). Aspen

No Single Optimum Form for All

- Physical differences prevent everyone from using the same form
  - Strength, bony structure, range of motion, tissue stiffness, mass distribution, general fitness, running history…

- Instead, there are key characteristics to avoid
  - Overstriding
  - Bounce
  - Compliance

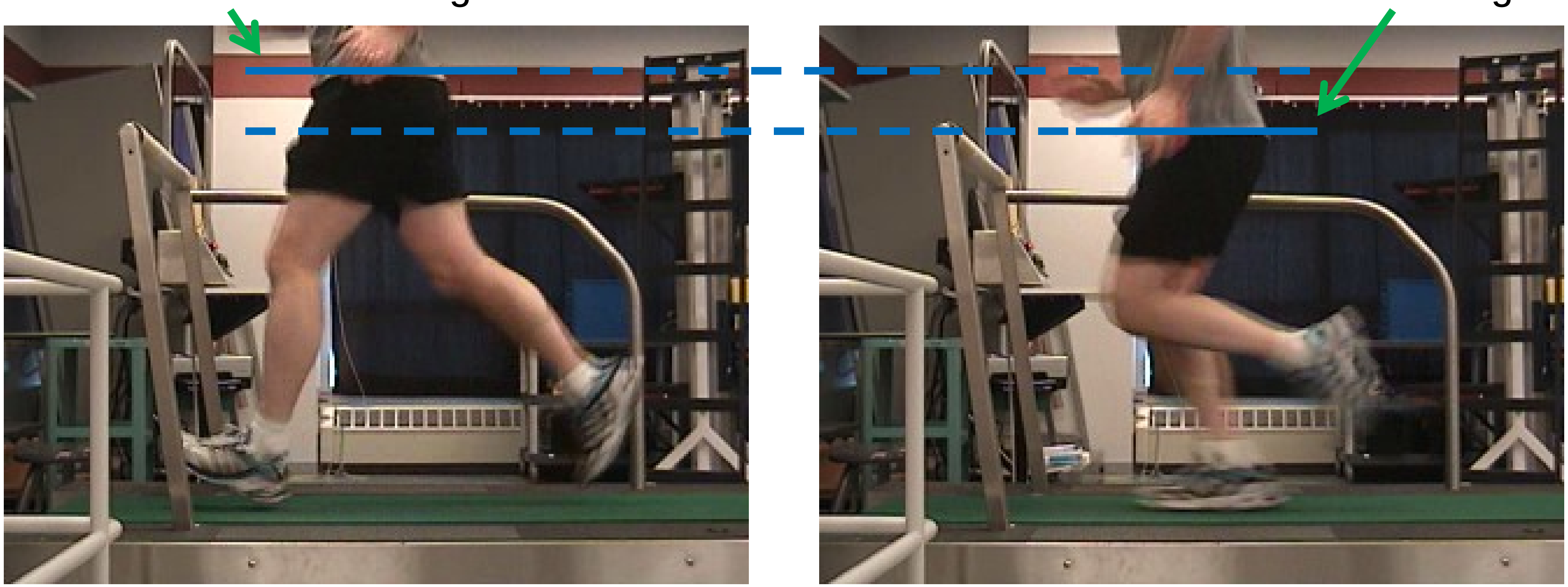
Avoid Overstriding



- Foot inclination angle
- Heel-COM distance
- Knee flexion angle
- Tibial angle

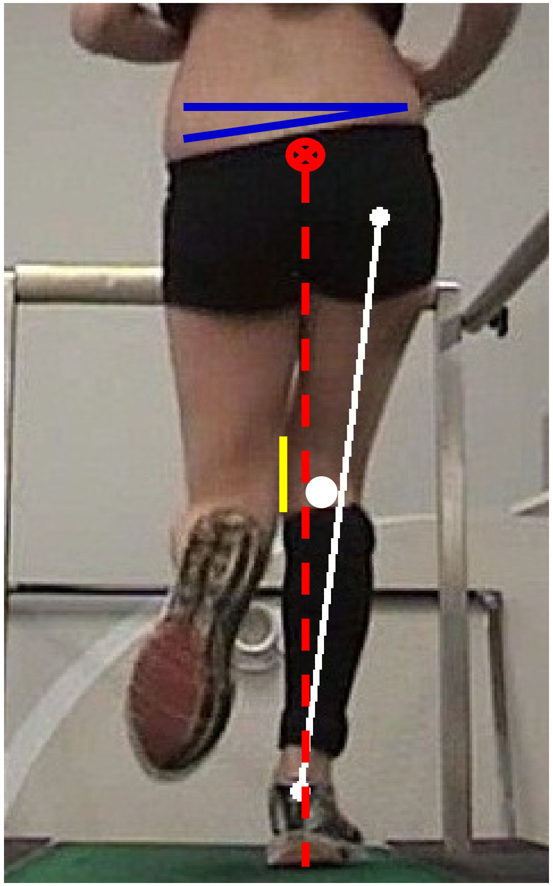
Avoid Bounce

- COM vertical displacement



Avoid Excessive Compliance

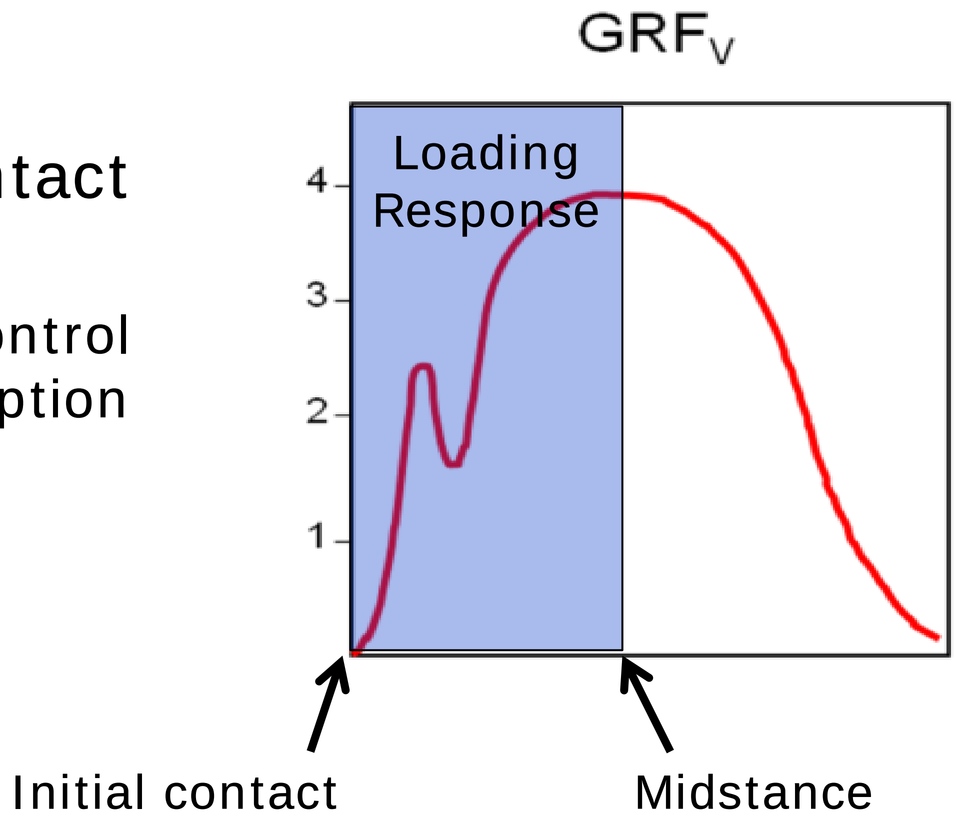
- Partially reflected in COM vertical displacement
- Evaluate frontal plane collapse



- Joint center alignment
- Lateral pelvic tilt
- Knee separation
- Foot-COM placement

Key Parameters

- Focus on loading response (initial contact to mid-stance)
  - characterize body control during energy absorption



Key Parameters

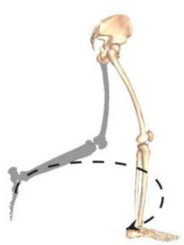
Frontal

- Midstance
  - Joint center alignment
  - Lateral pelvic tilt
  - Foot-COM placement
  - Knee separation
  - Rearfoot/shoe alignment

Sagittal

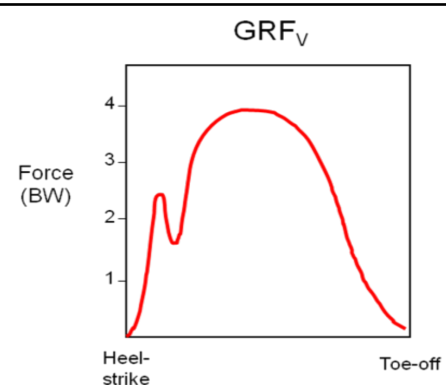
- Initial Contact
  - Foot-ground angle
  - Heel-COM distance
  - Knee flexion angle
  - Tibial angle
- Midstance
  - Max knee flexion angle
  - Max ankle dorsiflexion angle
- COM vertical displacement

Kinematic Predictors of Kinetics
Peak GRFv

		
Step Rate	Foot Inclination Angle at Initial Contact	Vertical Displacement of COM

↓

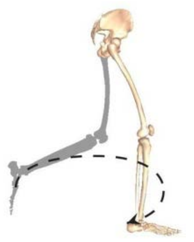
Peak Vertical GRF
(R^2=0.48)



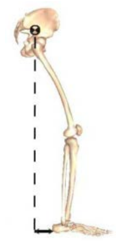
Wille et al. (2014). J Orthop Sports Phys Ther

Kinematic Predictors of Kinetics

Braking Impulse



Step Rate

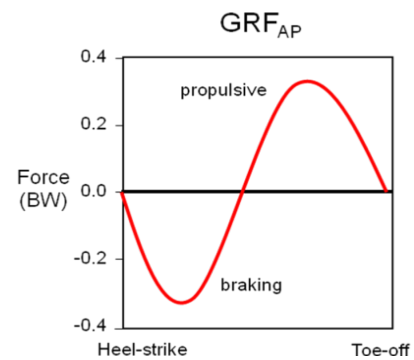


Heel to COM Distance at Initial Contact

Foot Inclination Angle at Initial Contact

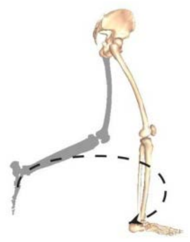
Vertical Displacement of COM

Braking Impulse
(R^2=0.50)



Wille et al. (2014). J Orthop Sports Phys Ther

Kinematic Predictors of Kinetics
Energy Absorption at Knee



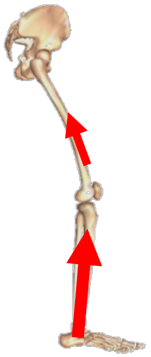
Step Rate

Foot Inclination Angle at Initial Contact

Peak Knee Flexion during Stance

↓

Mechanical Energy Absorbed about the Knee (R^2=0.58)



Wille et al. (2014). J Orthop Sports Phys Ther

Pseudo-quantitative Approach

- Estimate load to body based on posture at landing and midstance
- Use physical exam findings to interpret appropriateness of running mechanics
- Each parameter is assessed using 3-pt or 5-pt scale
  - Consideration for the inherent limitations with 2D video analysis

-2	**-1**	**Appropriate**	**+1**	**+2**

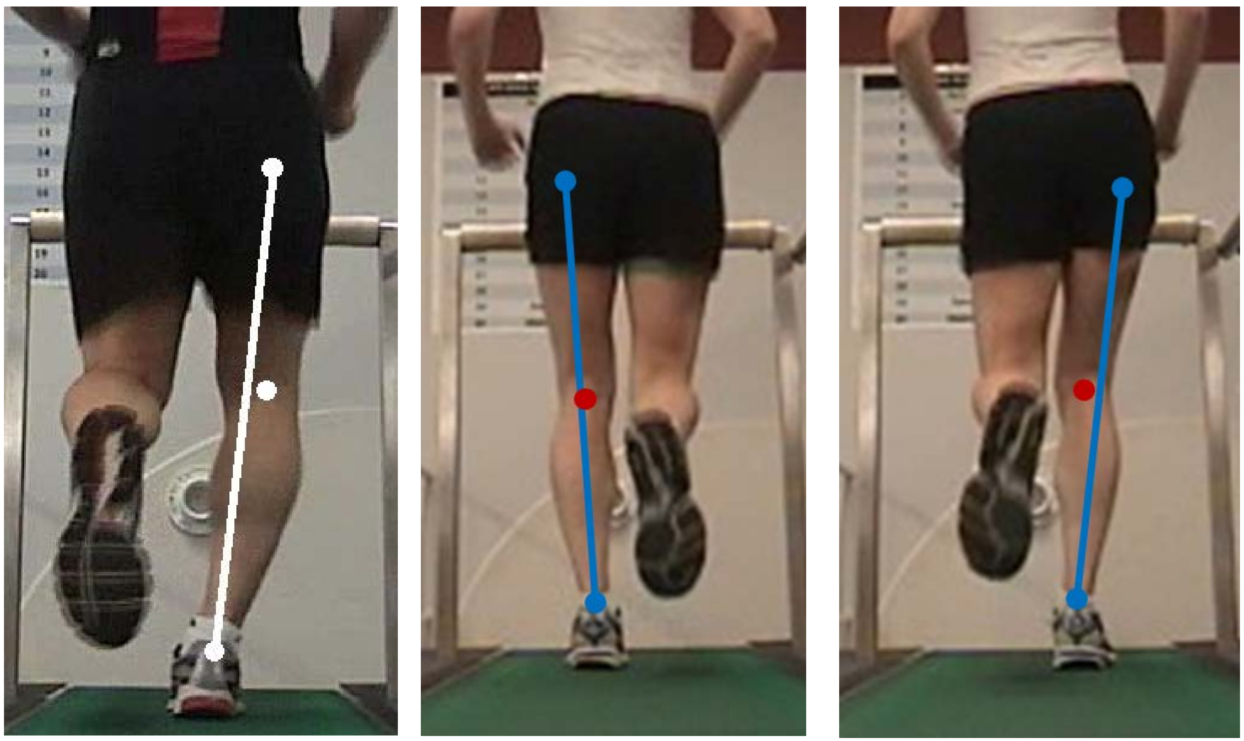
- Key parameters demonstrated strong agreement between raters ($\kappa > 0.80$)

Kotecki et al. (2013) J Orthop Sports Phys Ther

Joint Center Alignment
Midstance

Excessive lateral	Mild lateral	Appropriate (midline)	Mild medial	Excessive medial

Lateral Deviation | Appropriate | Medial Deviation



- Common Injuries:
  - PF pain
  - ITB syndrome
  - Greater trochanter syndrome
  - Piriformis syndrome

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

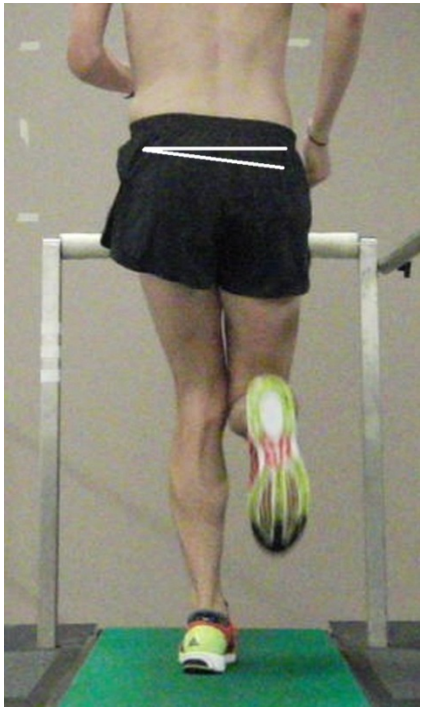
Lateral Pelvic Tilt

Midstance

Appropriate (3-5° males; 5-7° females)	Mild contralateral	Excessive contralateral

normal

mild

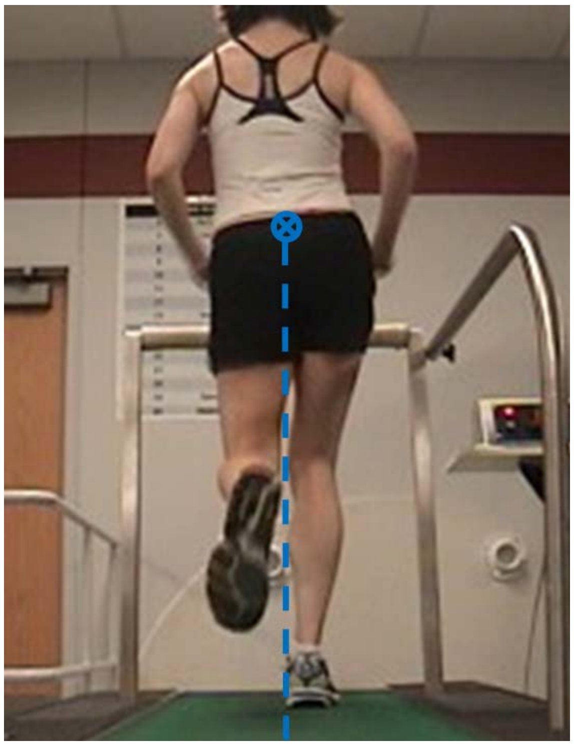


excessive

- Common Injuries:
  - Patellofemoral pain
  - ITB syndrome
  - Greater trochanter syndrome
  - Piriformis syndrome
  - Lumbopelvic pain

Foot-COM Placement at Midstance

Appropriate	Mild crossover	Excessive crossover



- As running speed increases, this distance decreases
- Common Injuries:
  - MTSS
  - Bone stress injuries
  - Greater trochanter syndrome

9:30 min/mile

Knee Separation at Midstance

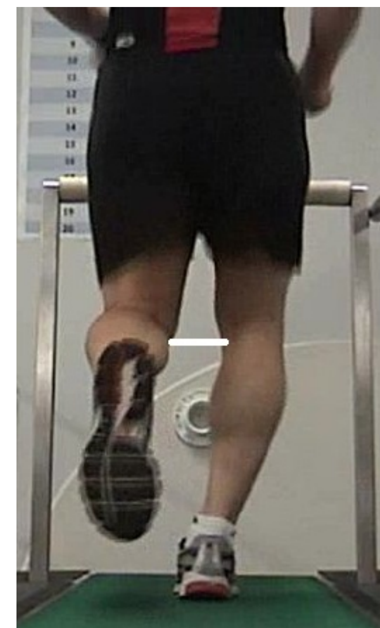
Narrow	Appropriate	Wide

Narrow with stance leg deviation

Narrow with swing leg deviation

Appropriate

Wide



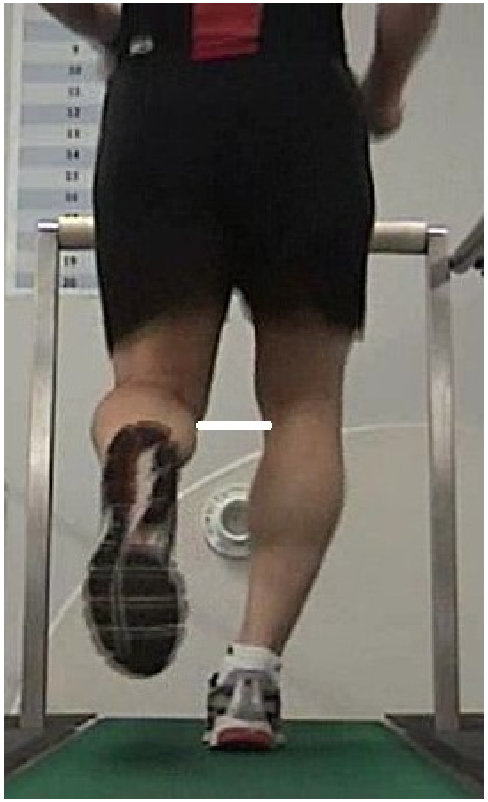
WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

Redundancy between Measures

Lateral knee alignment

Increased knee separation



Narrow foot placement

Foot Inclination Angle at Contact

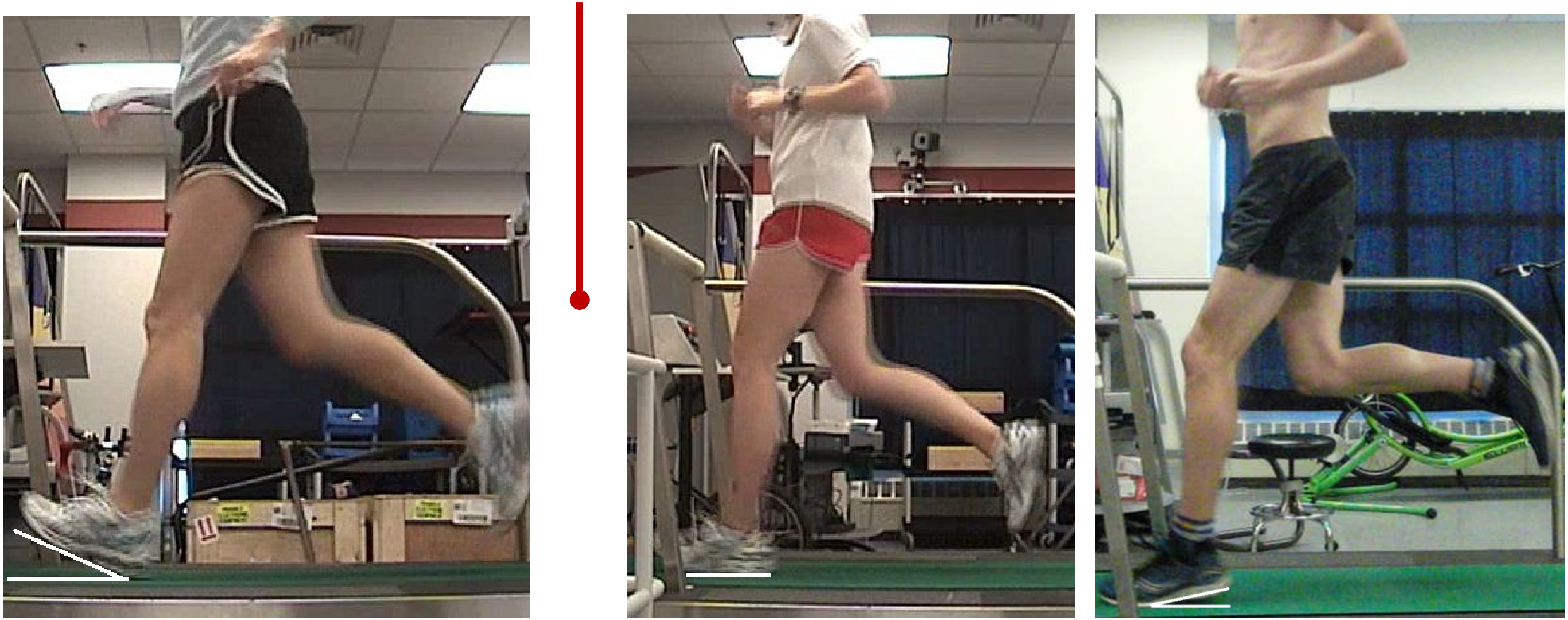
Heel-strike (>10°)	Rearfoot	Midfoot	Forefoot

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

Foot Inclination Angle at Contact

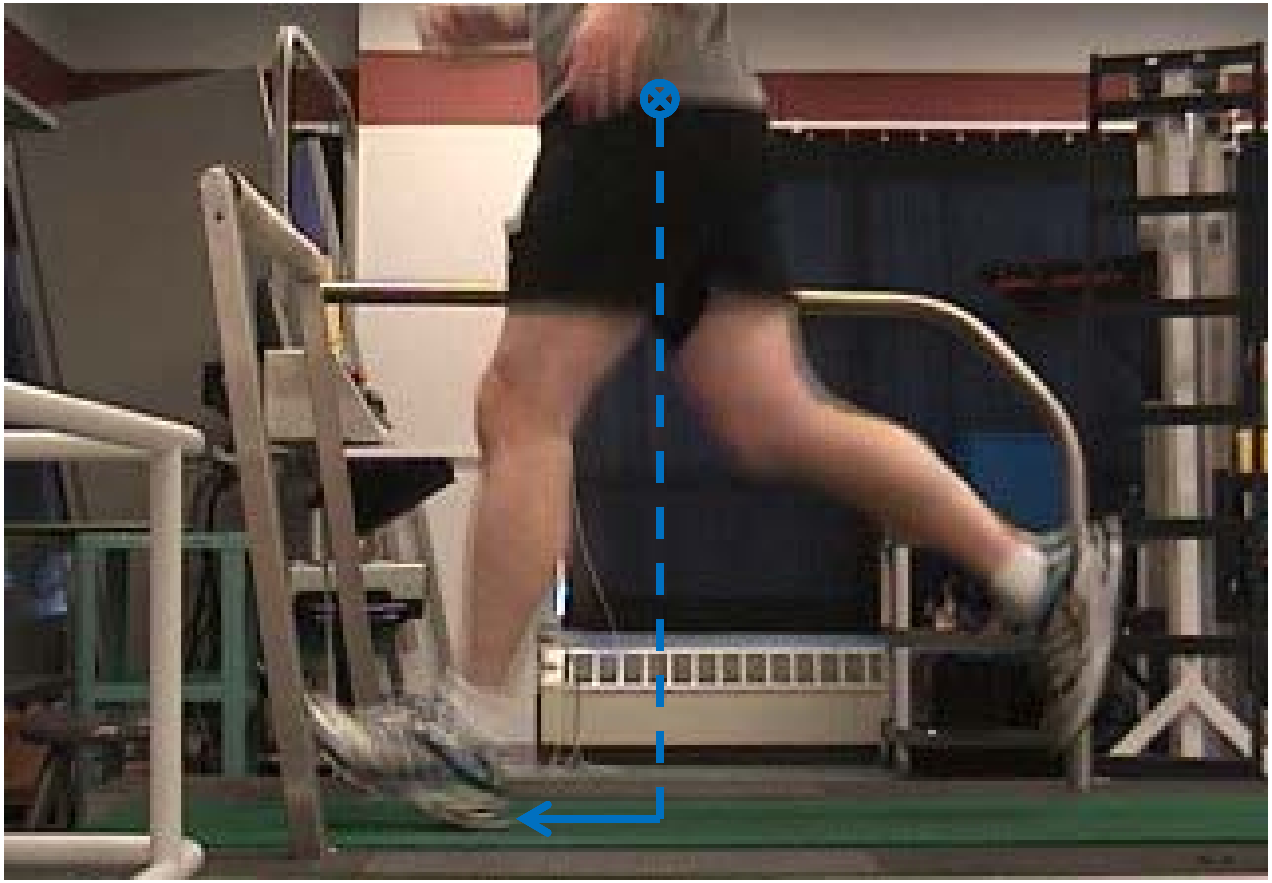
heel-strike rearfoot midfoot forefoot



WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

Horizontal Distance from Heel to COM at Contact



Knee Flexion Angle at Contact

Excessive decrease	Mild decrease	Appropriate (~20°)	Mild increase	Excessive increase

- Common Injuries:
  - Patellofemoral pain
  - Infrapatellar tendinopathy
  - ITB syndrome
  - Greater trochanter syndrome
  - Piriformis syndrome

Tibial Inclination Angle at Contact

Vertical	Mild inclination	Excessive inclination

- Common Injuries:
  - MTSS
  - Bone stress injuries
  - Exertional compartment syndrome

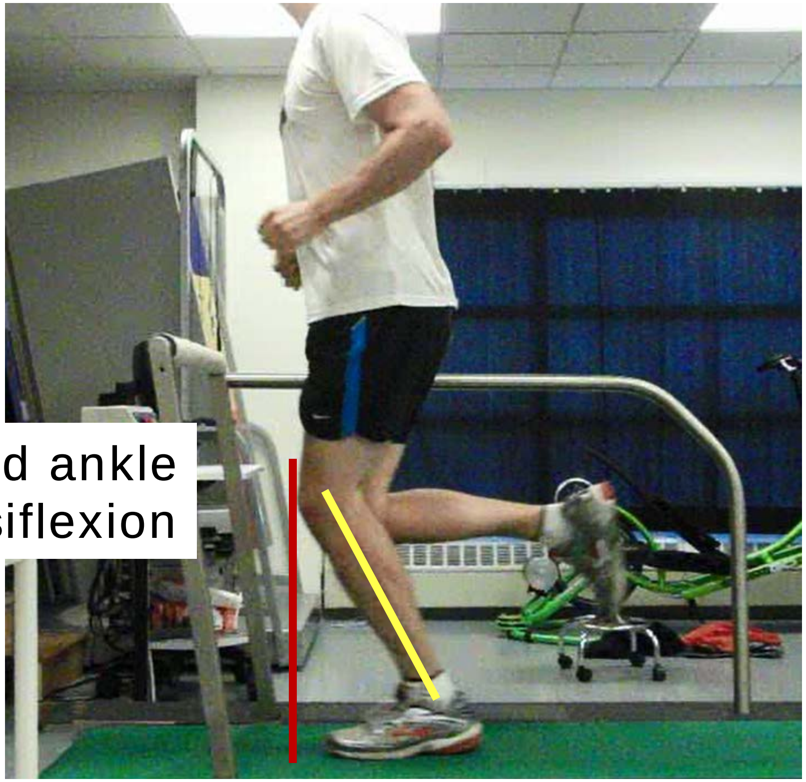
Maximum Knee Flexion Angle

Excessive decrease	Mild decrease	Appropriate (~40°)	Mild increase	Excessive increase

- Common Injuries:
  - Patellofemoral pain
  - Infrapatellar tendinopathy
  - ITB syndrome
  - Greater trochanter syndrome

Ankle Dorsiflexion at Midstance

Decrease	Appropriate (knees over toes)	Increase



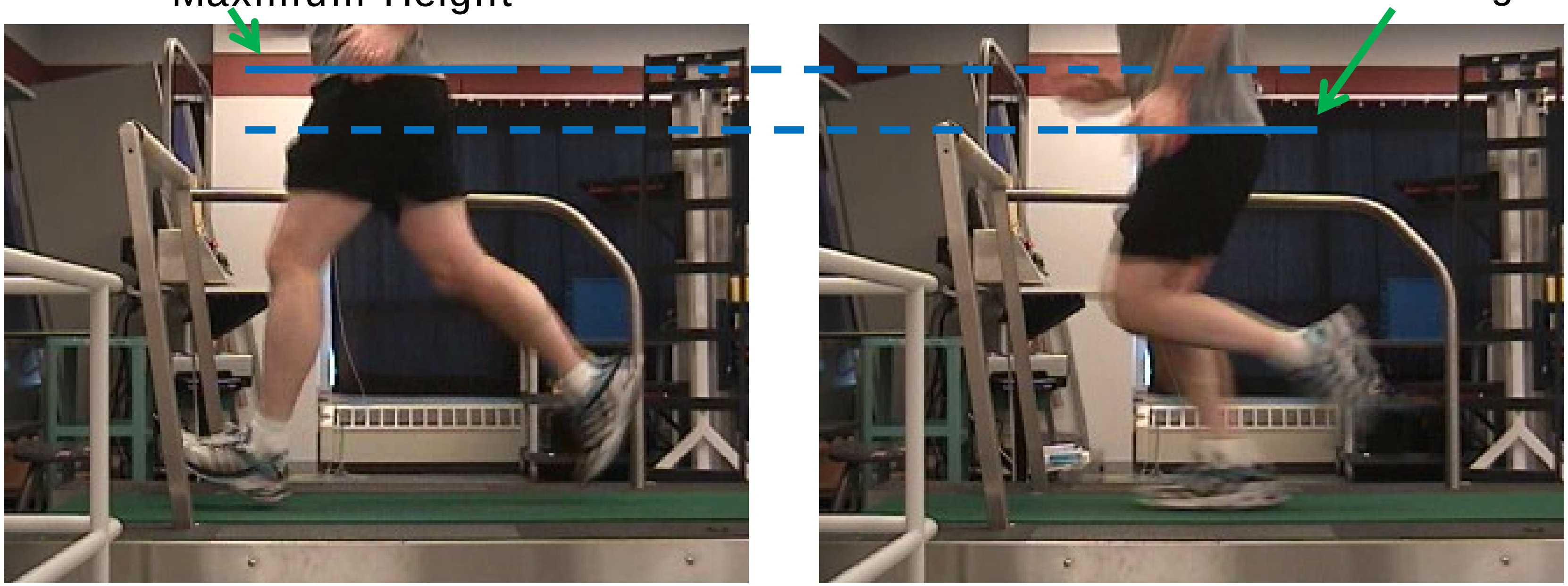
- Common Injuries:
  - Calf strains
  - Achilles tendinopathy
  - Plantar fasciitis

COM Vertical Displacement

Appropriate (6-8cm)	Mild Increase	Excessive Increase

Maximum Height

Minimum Height



Mid-flight

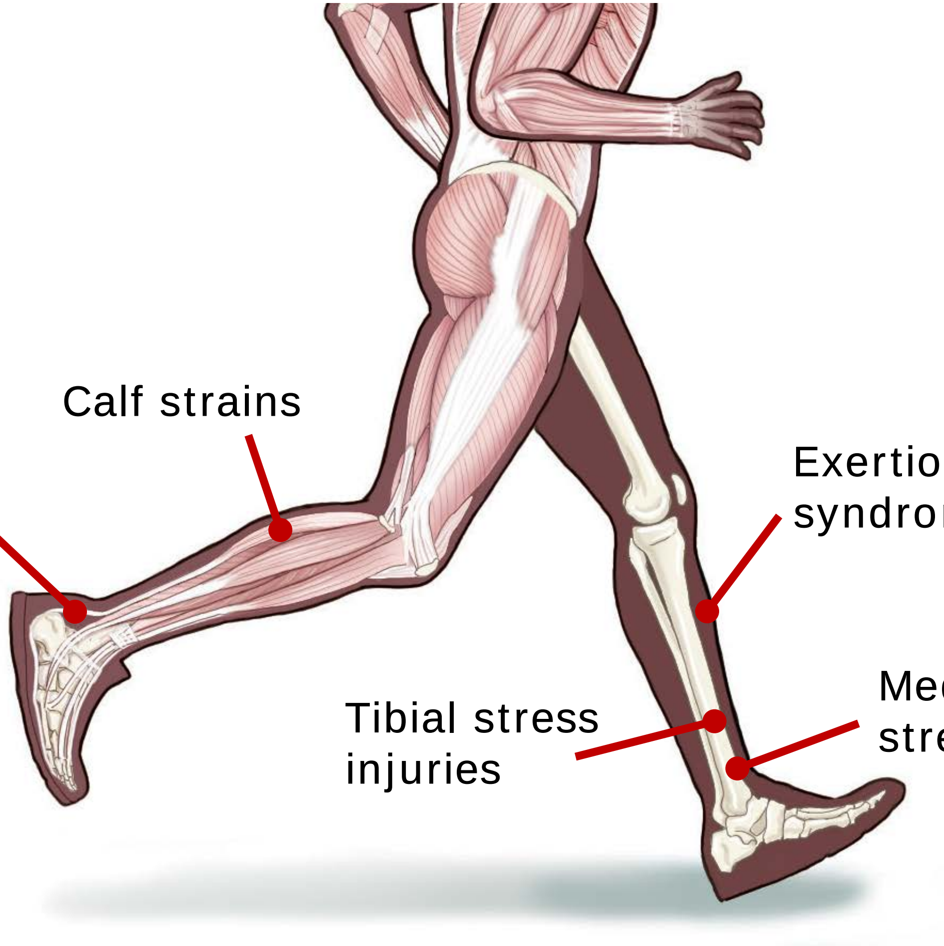
Midstance

Putting it all Together

- 17 y/o with chronic knee pain and tibial stress reactions

9:00 min/mile 168 steps/min

Lower Leg Injuries and Running



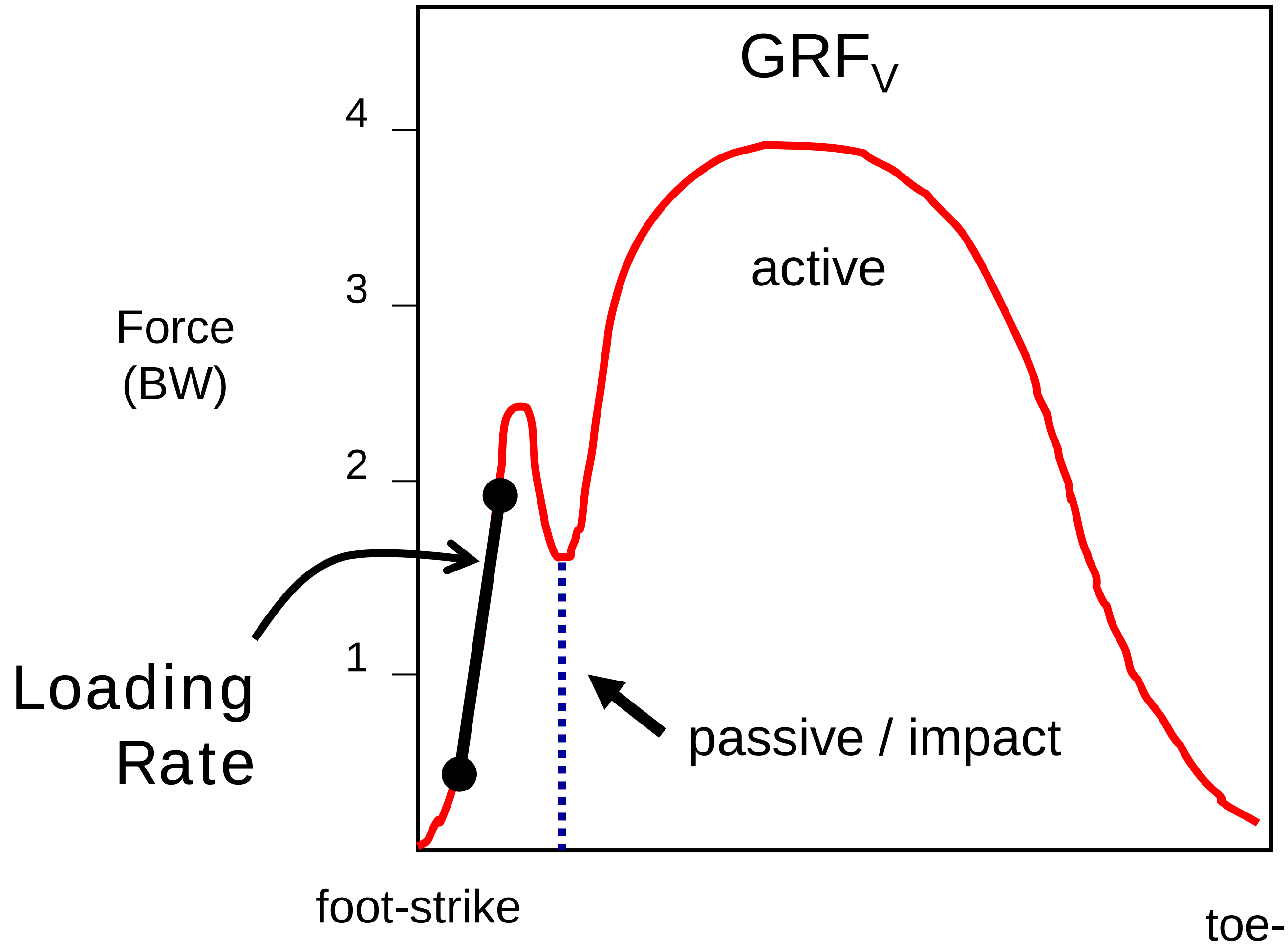
Tibial Stress Injuries

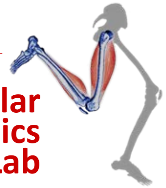
- Mechanics of concern:
  - Impact loading rate
  - Braking impulse
  - Tibial inclination angle at initial contact
  - COM vertical displacement

- Meta-analysis results showed significant differences between the vertical loading rates of the those with and without prior lower-limb stress fractures

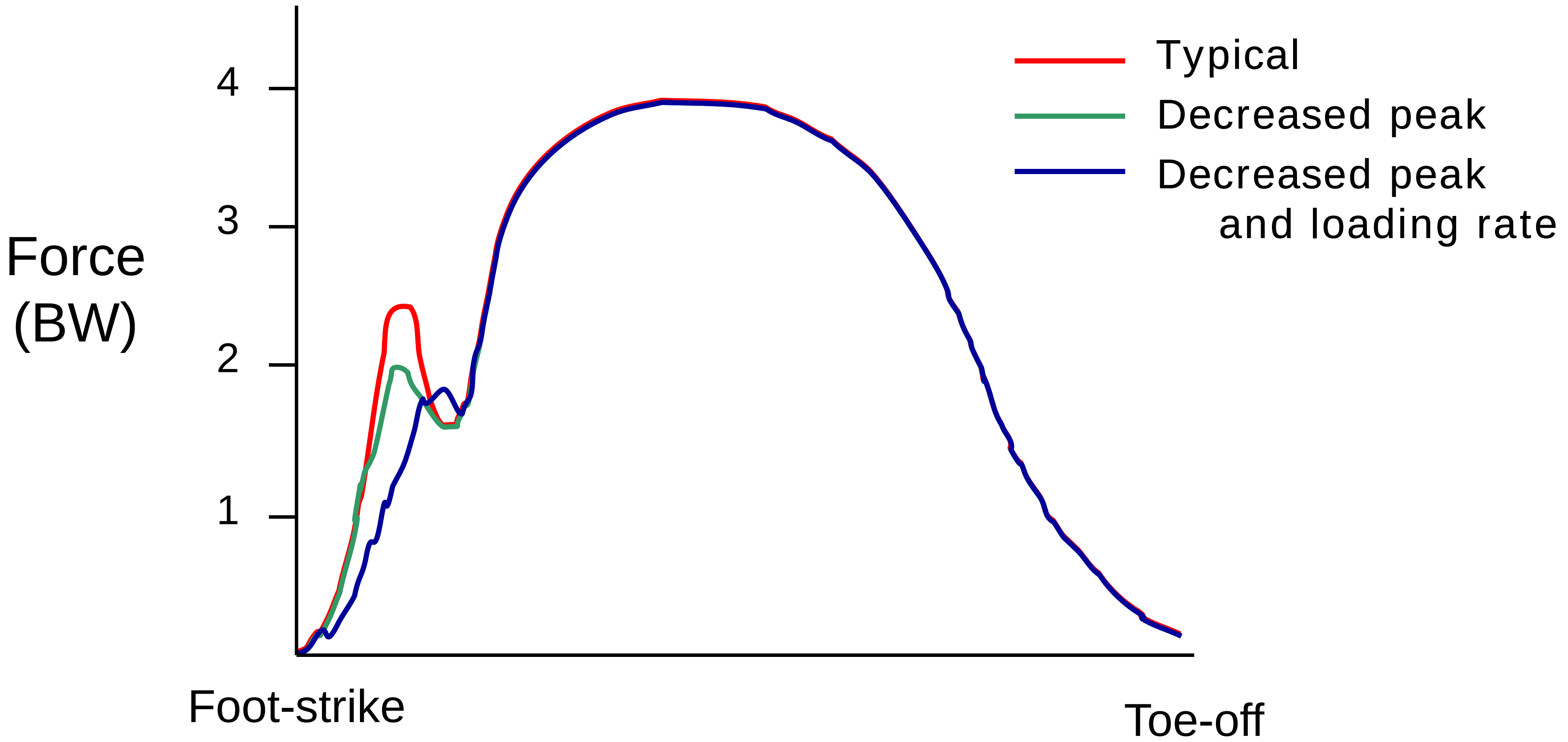
Zadpoor and Nikyooan (2011) Clin Biomech

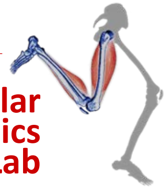
Running Forces and Loading Rate



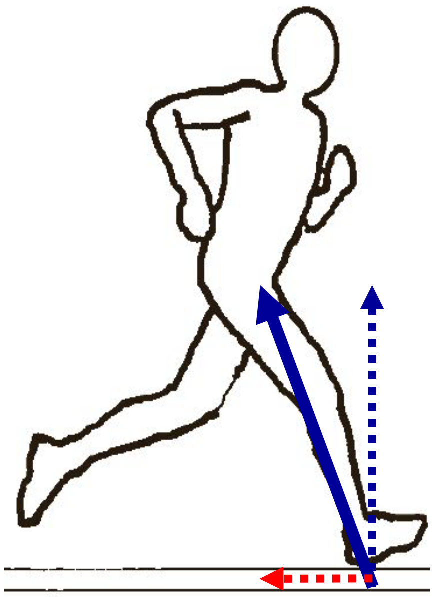


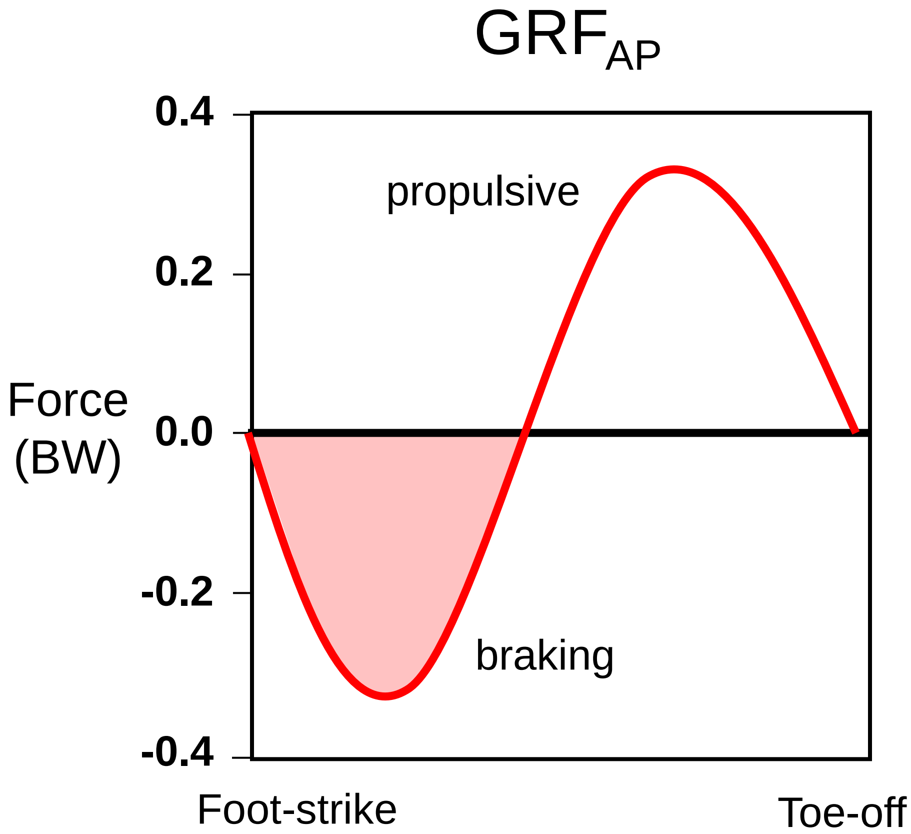
Decreased Loading Rate





Braking Impulse

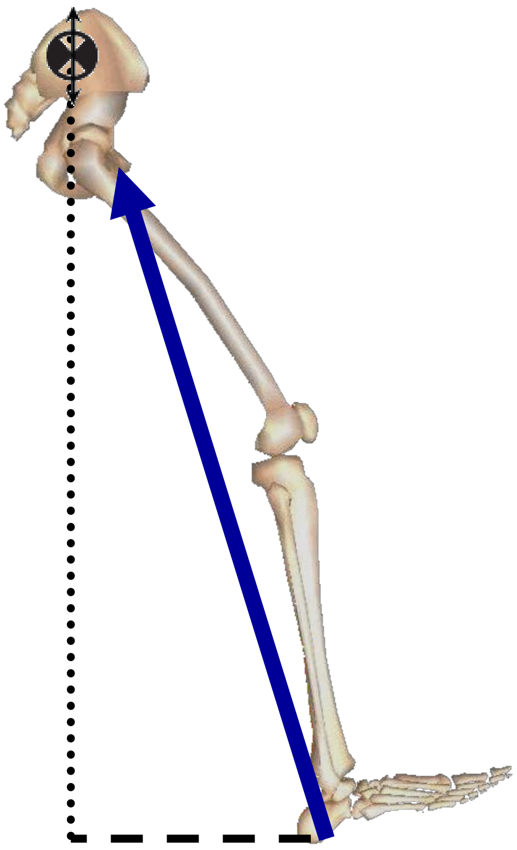




Stride Length

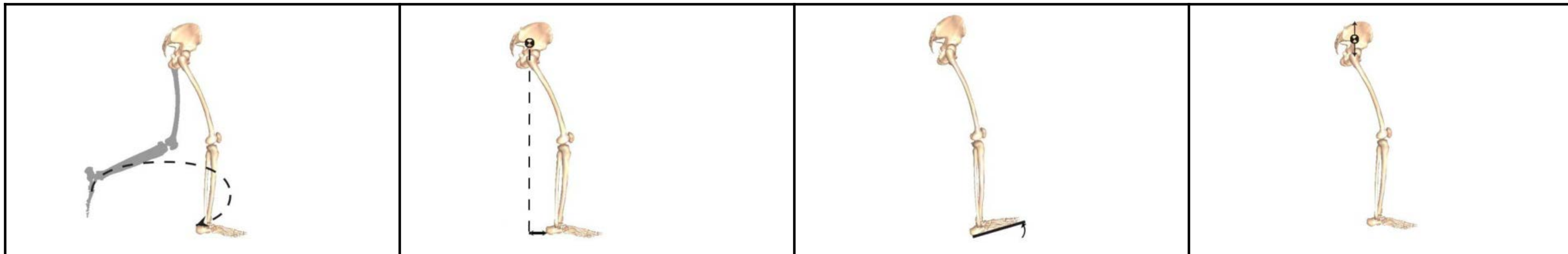
- Farther the foot hits the ground in front of the body's COM (longer stride), the greater the braking impulse

- Body has to overcome this braking impulse to maintain speed



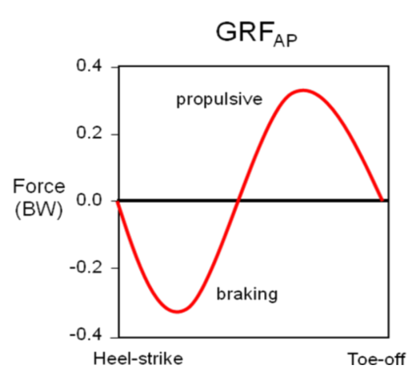
Kinematic Predictors of Kinetics

Braking Impulse



Step Rate	Heel to COM Distance at Initial Contact	Foot Inclination Angle at Initial Contact	Vertical Displacement of COM

Braking Impulse
(R^2=0.50)

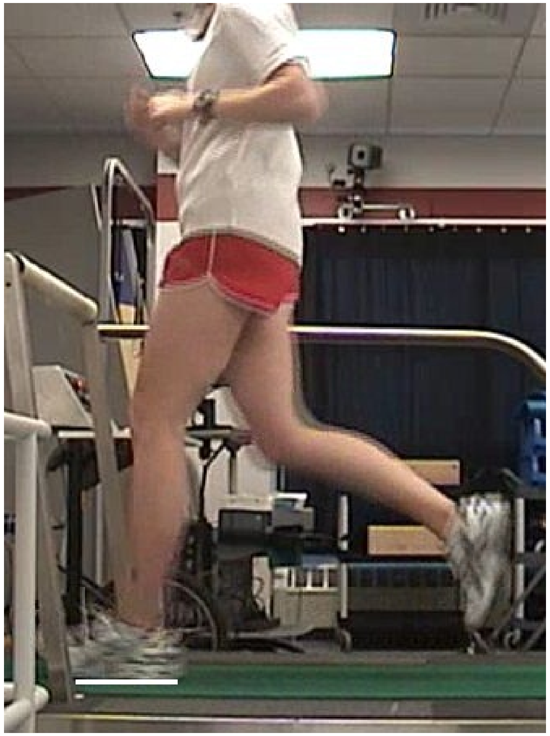


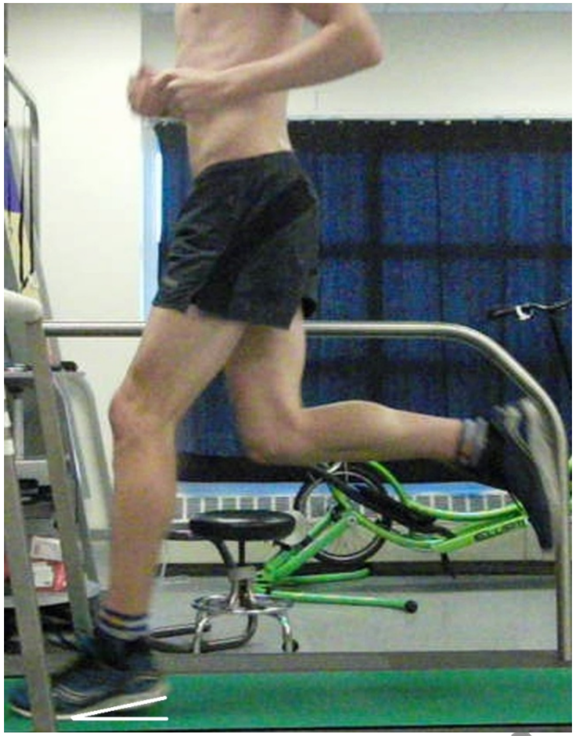
Wille et al. (2014). *J Orthop Sports Phys Ther*

Foot Inclination Angle at Contact

Heel-strike (>10°)	Rearfoot	Midfoot	Forefoot

heel-strike rearfoot midfoot forefoot



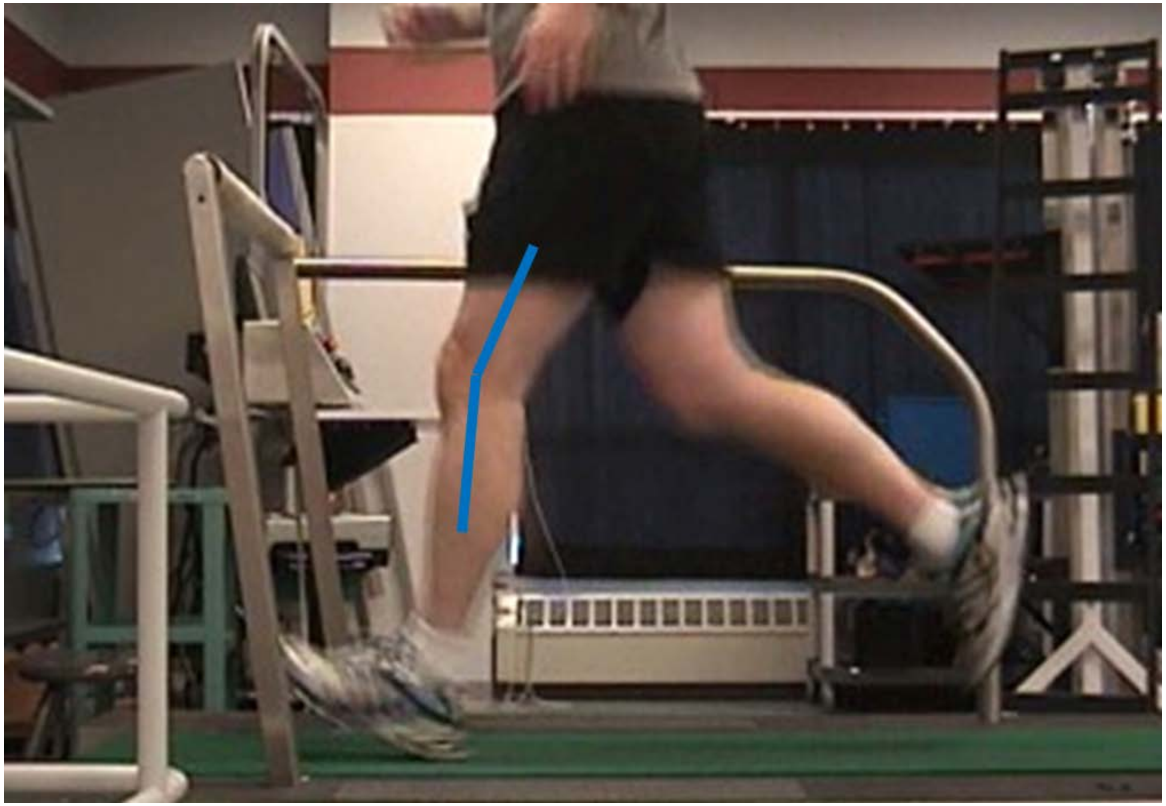


WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

Knee Flexion Angle
Initial Contact

Excessive decrease	Mild decrease	Appropriate (~20°)	Mild increase	Excessive increase



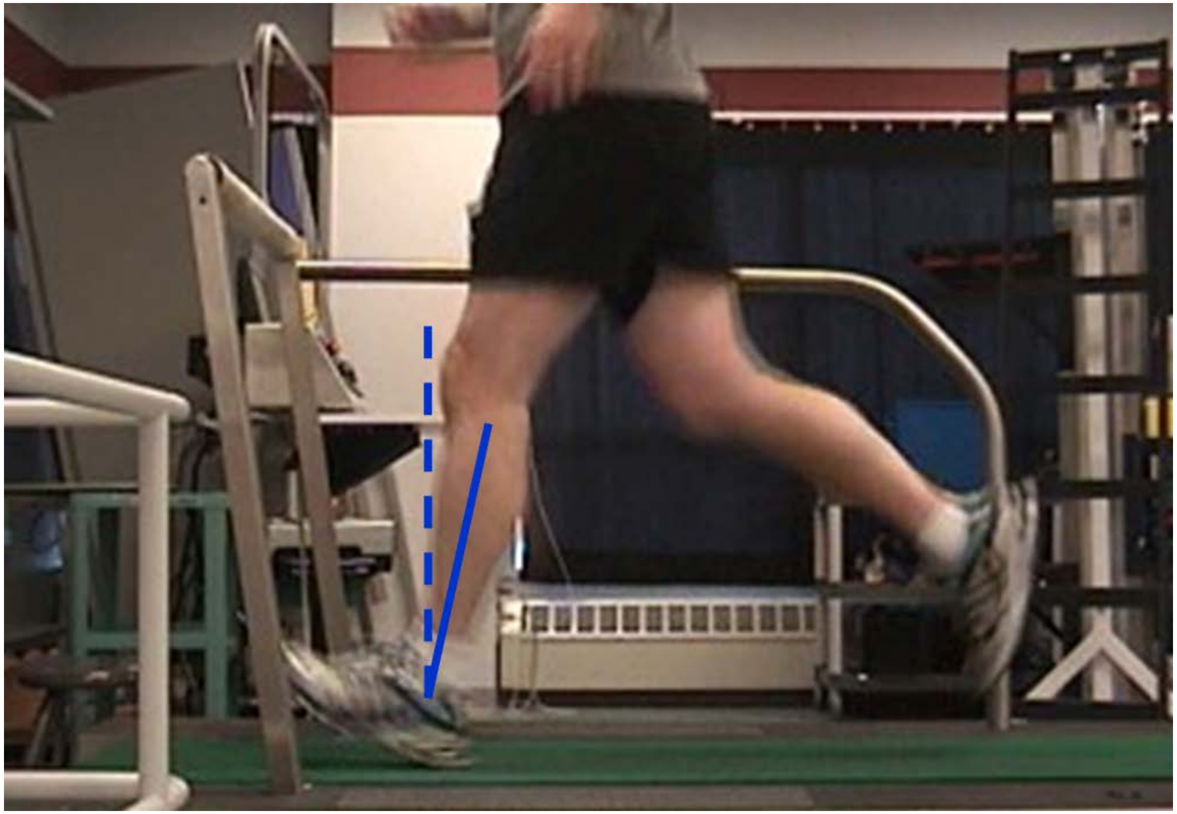
WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

Tibial Inclination Angle

Initial Contact

Vertical	Mild inclination	Excessive inclination



Stride Length

- Reduction in stride length reduces risk of tibial stress injury

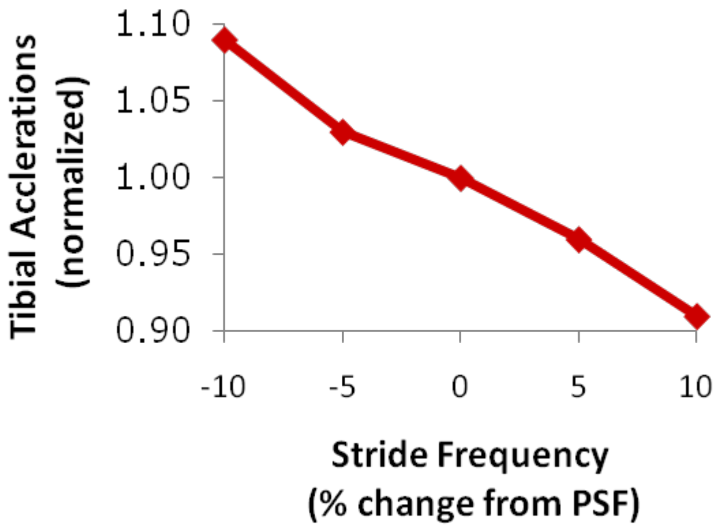
Edwards et al. (2009) *Med Sci Sports Exerc*

- positively effects:
  - loading rate
  - braking impulse
  - tibia inclination angle
  - COM vertical displacement
- Increasing step rate is simple strategy to teach/learn
  - Maintain constant speed

Step Rate and Tibial Accelerations

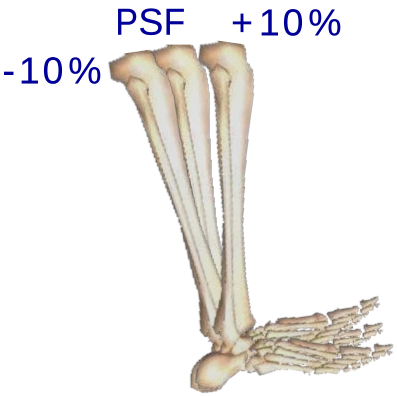
- Decreased tibial accelerations with increased step rate
  - Constant speed

Clarke et al. (1995) *J Sports Sci*



- More vertical leg posture at initial contact

Farley and Gonzalez (1996) *J Biomechanics*

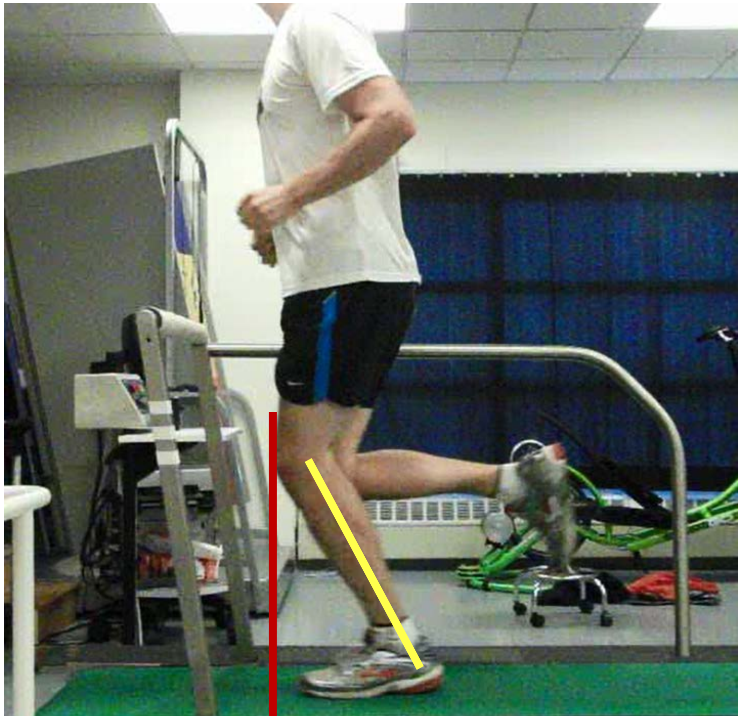


Calf and Achilles Injuries

- Running mechanics of concern:
  - Peak ankle dorsiflexion during stance
  - COM vertical displacement

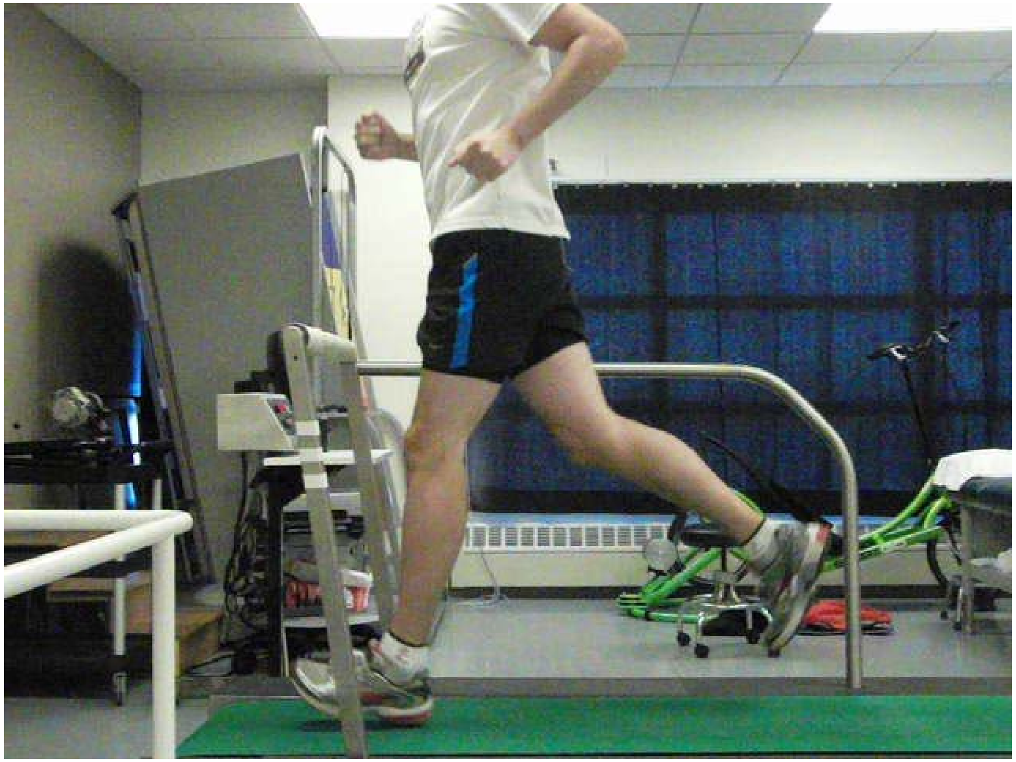
Provocative Running Mechanics

- Pain is typically during propulsive phase of stance (50-100%)
  - Generally not during loading response
- Excessive ankle dorsiflexion during midstance
  - Should be assessed relative to ankle dorsiflexion observed in weightbearing
  - excessive strain and wrapping prior to initiation of concentric contraction
- If medial insertional pain, look for high rate of pronation during contact



Achilles Case

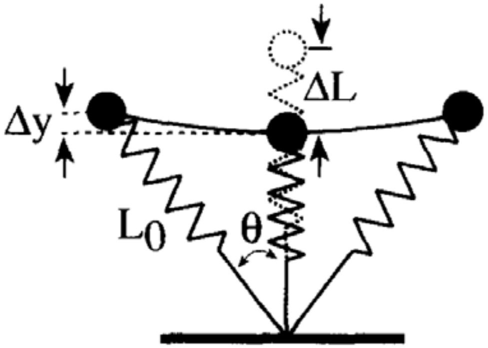
9:30 min/mile; 150 steps/min



- 37 y/o male
- Recurrent Achilles symptoms past 2 yrs
- Midportion tendon pain with palpation (5cm from insertion)
- Limited weightbearing DF
- COM vertical displacement ~11-12 cm
- Increased peak dorsiflexion in stance

How to Reduce Dorsiflexion Angle?

- Increased ankle dorsiflexion is related to increased knee flexion
- Reduce both by increasing lower extremity stiffness (increase step rate)
  - Spend less time on the ground



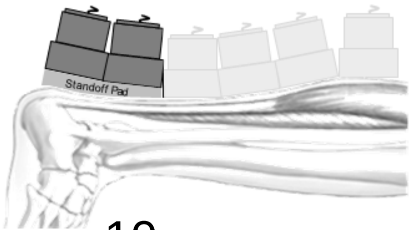
Morin et al. (2007) *J Biomechanics*
Farley and Gonzalez (1996) *J Biomechanics*

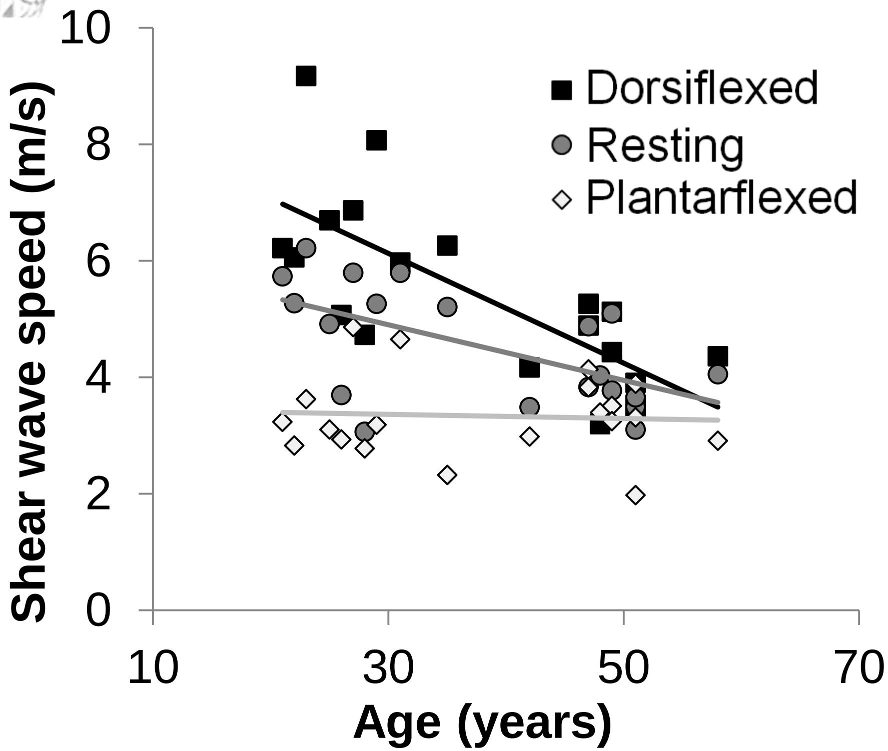
Heavy Load Eccentrics

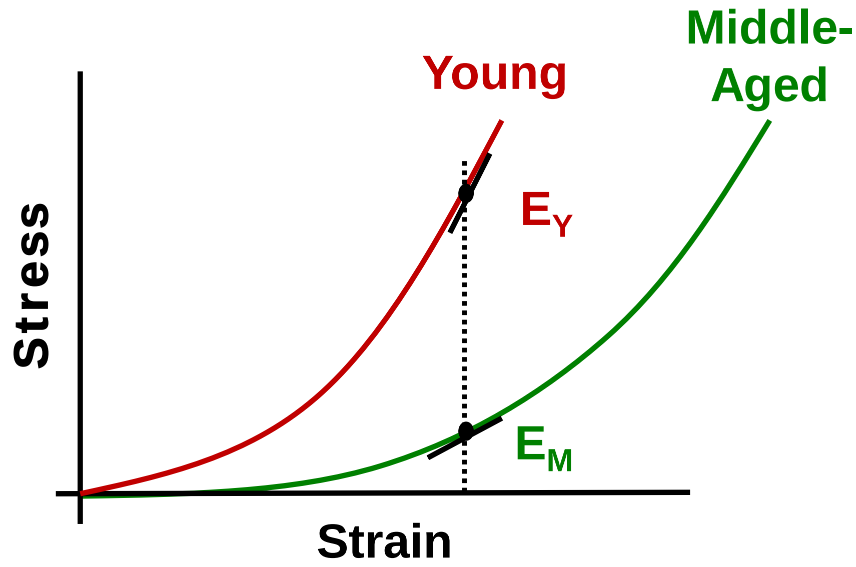
- Proven benefit for Achilles tendinopathies
  - "2-up, 1-down"
  - midportion and insertional, just change range
- Incorporate into recovery from calf strain, when appropriate
  - Generally after 7-10 days depending on severity

- Consider as preventative exercise for runners over age of 35 yr
  - Potentially slow the increased compliance of Achilles tendon associated with aging

Gastrocnemius Aponeurosis



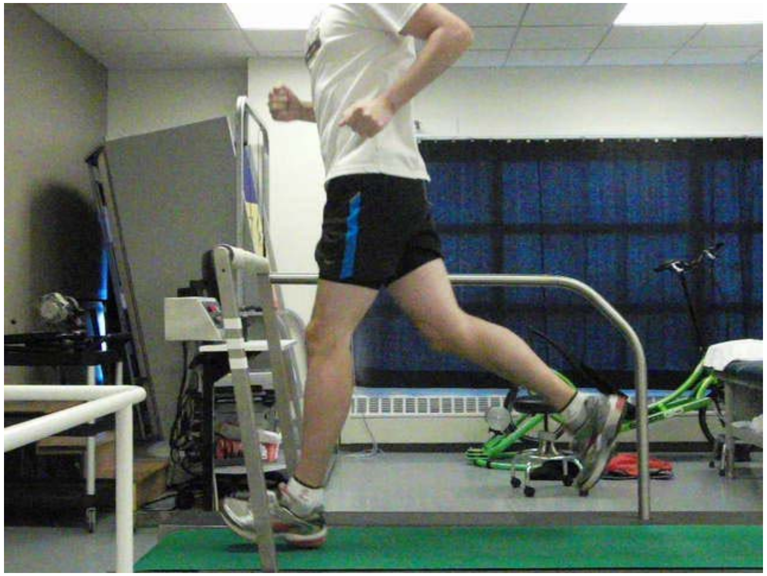




Slane LC (2014) Dissertation, UW-Madison

Case Outcome

Pre
9:30 min/mile @ 150 steps/min



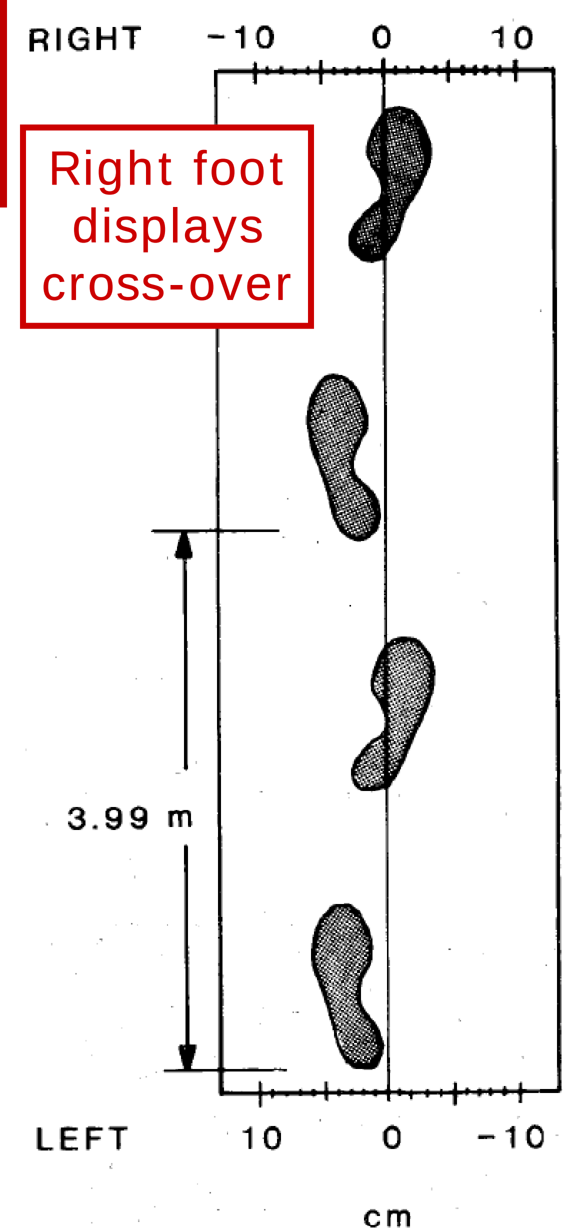
4wks post
9:30 min/mile @ 160 steps/min

- 4 wk follow-up
  - No pain or symptoms
  - 80% back to pre-injury level; remaining limitation is reduced mileage

Medial Tibial Stress Syndrome

- Running mechanics of concern:
  - Foot-inclination angle
  - Midline cross-over
  - Foot pronation
  - Toe-out

Foot Placement



Step Width

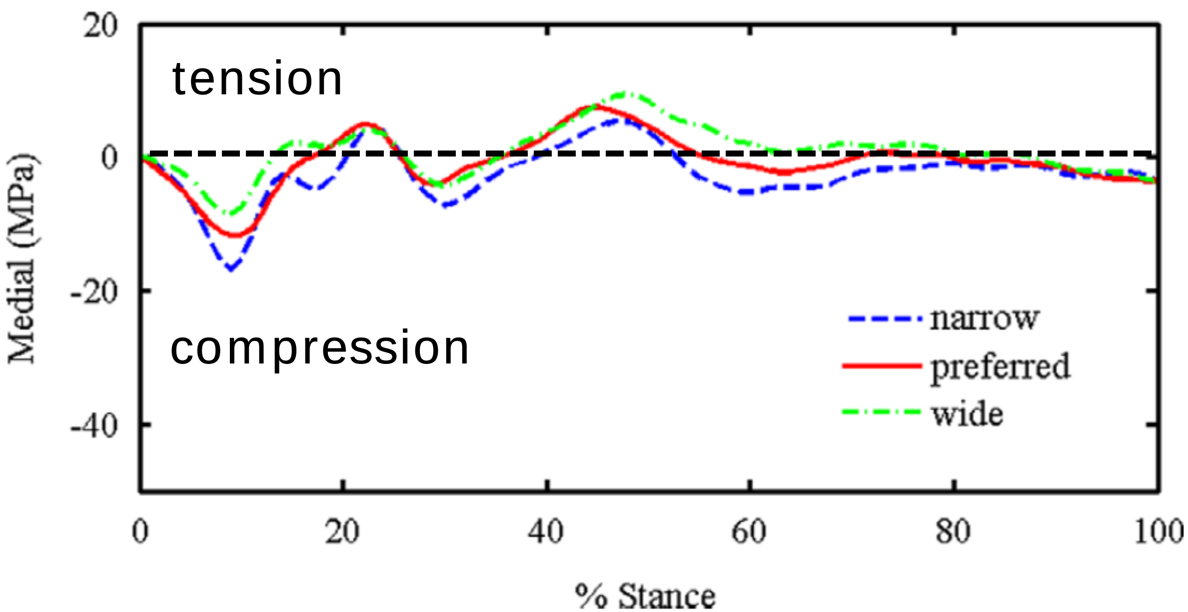
- Decreases with increasing speed

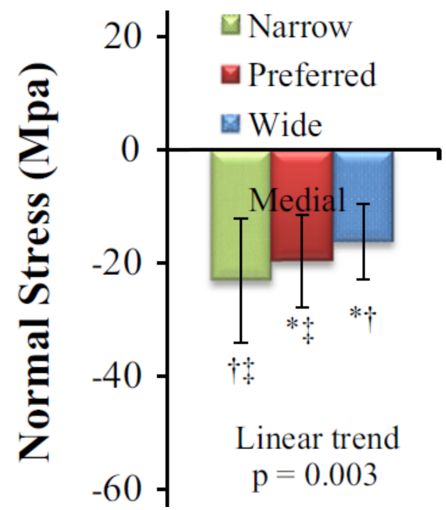
Relative to COM

- Crossover

Bone Stress and Cross-over

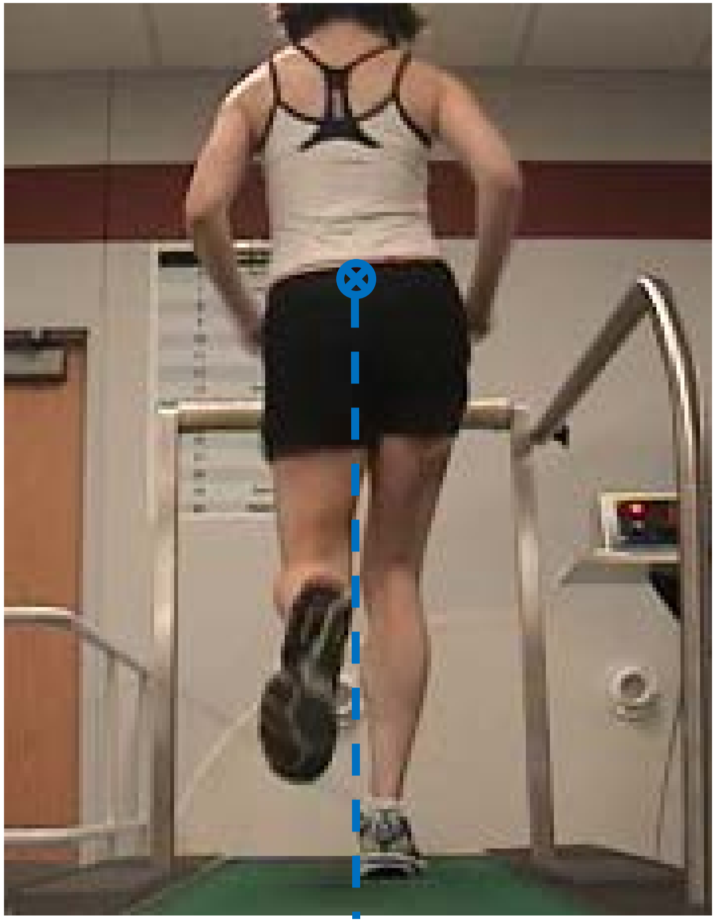
- Tibial stress associated with step width
  - Greater compression along medial aspect of tibia with narrow step width





Meardon and Derrick (2014). *J Biomech*

Foot-COM Placement at Midstance



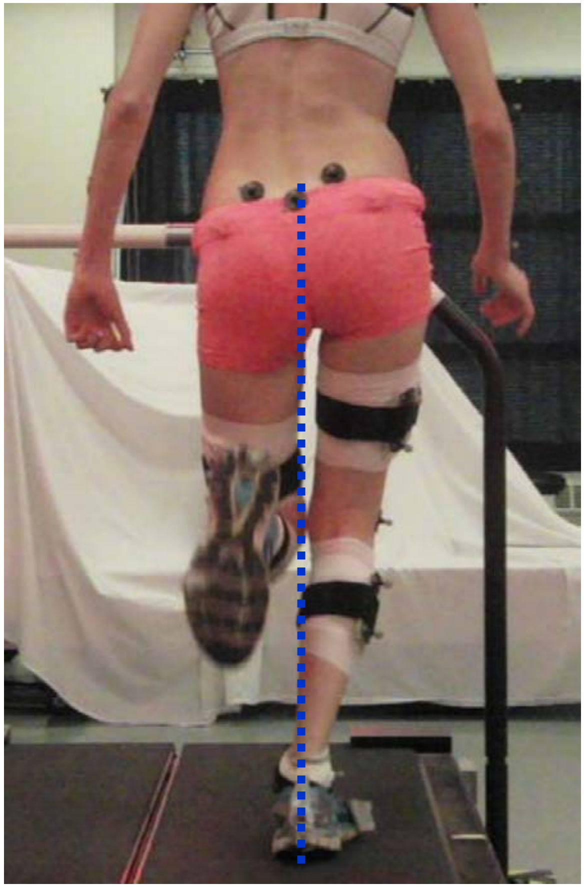
- Location of the foot with respect to the whole body's line of gravity (LOG)
- As running speed increases, this distance decreases

9:30 min/mile

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab

MTSS and Crossover



How to Reduce Cross-over?

- Increase step width
  - Verbal cueing
  - Mirror retraining

- Commonly overcorrected at start of retraining

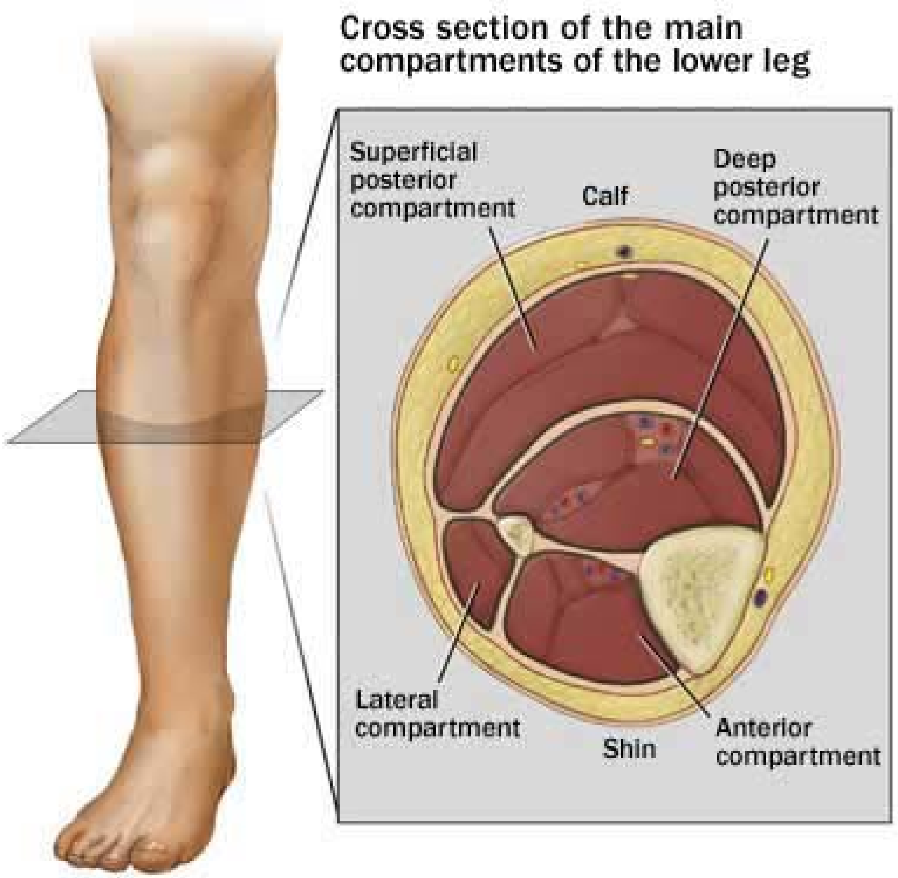
- May influence performance
  - 9% net increase in metabolic power with 8% increase in step width

Arellano and Kram (2011) *J Biomech*

- Address gluteal muscle weakness/firing
  - Narrow step width may be strategy to create stable stance position thereby reducing need for muscular stabilization at hip

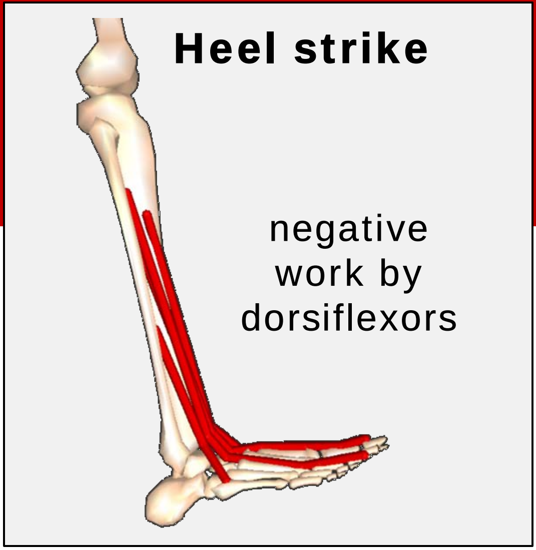
Exertional Compartment Syndrome

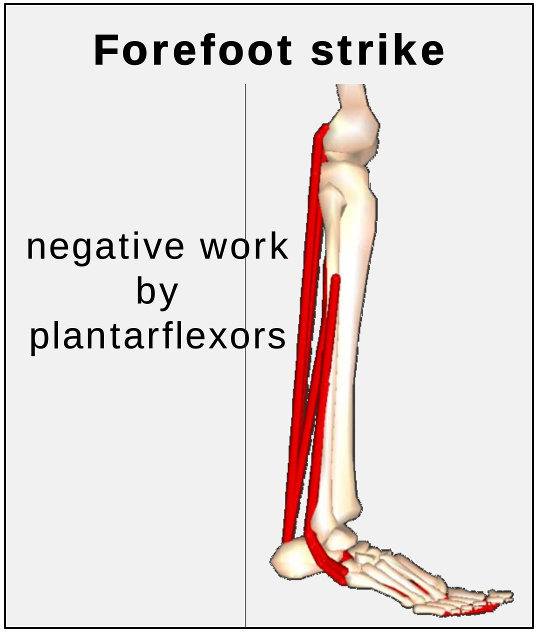
- Running mechanics of concern:
  - Foot-inclination angle
  - Ankle dorsiflexion during swing
    - Rate and magnitude



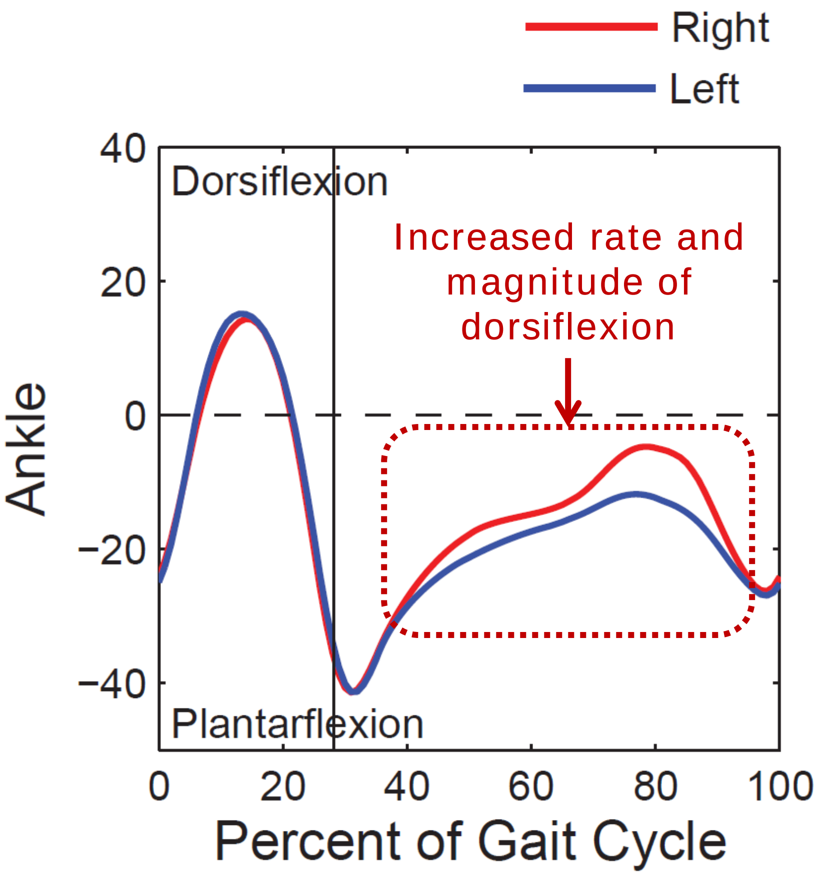
Forefoot Strike

- 2 patients with chronic exertional compartment syndrome
  - 1: 4yr history of bilateral symptoms
  - 2: 7 months s/p right fasciotomy with symptom return bilateral
- Retraining: emphasis on forefoot landing and Pose technique
  - 3x/wk (1hr each) for 6 weeks
- Clinical outcomes:
  - Reduced intracompartmental pressures post-running
  - 6wk F/U: GROC "great deal better"
  - 7 month F/U: still running pain-free





What about Swing Phase?



Summary

UW Health
University of Wisconsin Sports Medicine

UW Sports Medicine Runners' Clinic
2D Video Analysis

UW Neuromuscular Biomechanics Lab

- Designed with the common clinician in mind
  - Minimal overhead
  - Reimbursable
  - 60min or less

Sagittal Plane

	Left	Right
Initial Contact		
Foot-Strike Pattern	Heel Strike Rear Foot Mid-Foot Forefoot Toe-Strike	Heel Strike Rear Foot Mid-Foot Forefoot Toe-Strike
Tibial Inclination (vertical or mild inclination)	Vertical Mild Inclination Excessive Inclination	Vertical Mild Inclination Excessive Inclination
Knee Flexion Angle (~20°)	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase
Mid-Stance		
Knee Flexion Angle (~40°)	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase	Excessive Decrease Mild Decrease Appropriate Mild Increase Excessive Increase
Ankle Dorsiflexion Angle (5-20°, relative to WB)	Appropriate Mild Inclination Excessive Inclination	Appropriate Mild Inclination Excessive Inclination
Pushoff		
Hip Extension Angle (0-5°)	Excessive flexion Mild flexion Appropriate Mild extension Excessive extension	Excessive flexion Mild flexion Appropriate Mild extension Excessive extension
Pelvic Tilt (5-10°)	Excessive anterior Mild anterior Appropriate Mild posterior Excessive posterior	Excessive anterior Mild anterior Appropriate Mild posterior Excessive posterior
Lumbar Lordosis (slight extension)	Excessive flexion Mild flexion Appropriate Mild lordosis Excessive lordosis	Excessive flexion Mild flexion Appropriate Mild lordosis Excessive lordosis
Full Gait Cycle		
COM Vertical Excursion (6-8 cm)	Appropriate Mild increase Excessive increase	Appropriate Mild increase Excessive increase
Forward Trunk Lean (5-10° forward)	Excessive Backward Mild Backward Appropriate Mild Forward Excessive Forward	

Thank You

Madison, WI, USA

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UW Neuromuscular Biomechanics Lab