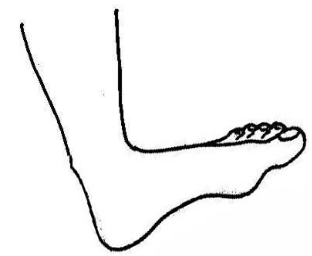
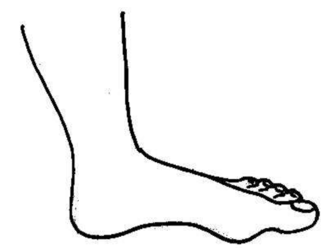
Barefoot Running

Have sneakers changed the way we run?

Why Barefoot Running?

- Humans evolved to run long distances without the assistance of footwear
- An estimated 30% of runners experience some type of injury each year, often in the feet or lower legs
- Anecdotal evidence suggests that individuals who grow up running long distances without supportive footwear sustain fewer injuries

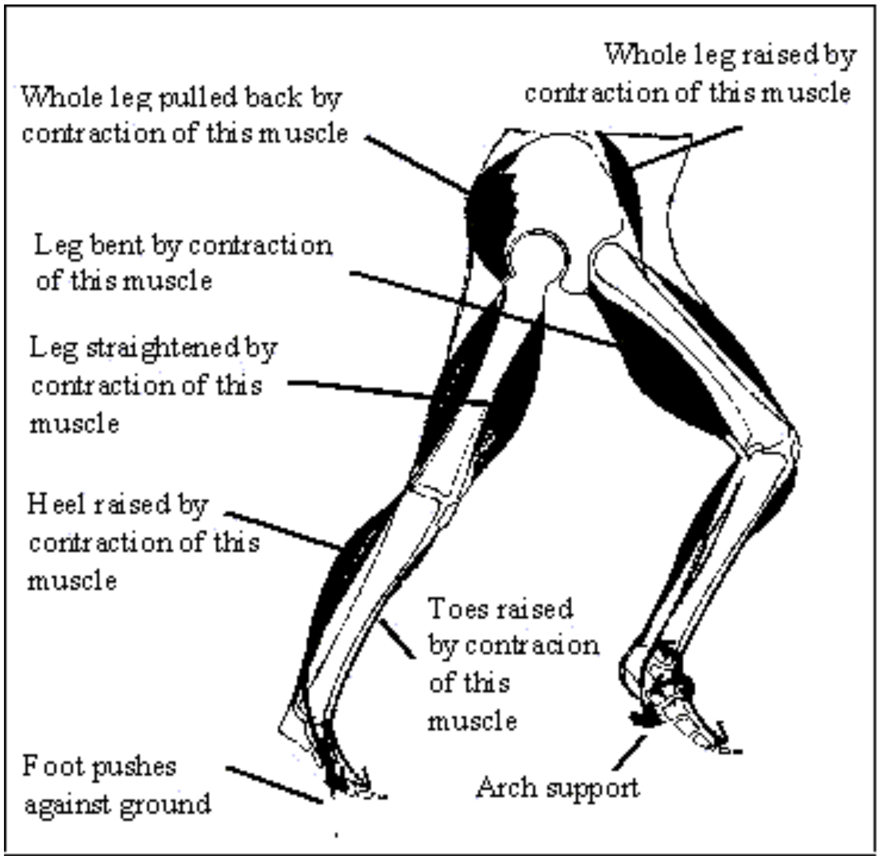
Foot-Strike Techniques

Heel Strike	Heel lands first, followed by rotation towards the forefoot	
Midfoot Strike	Entire foot lands simultaneously	
Forefoot Strike	Ball of the foot lands first, followed by the heel	

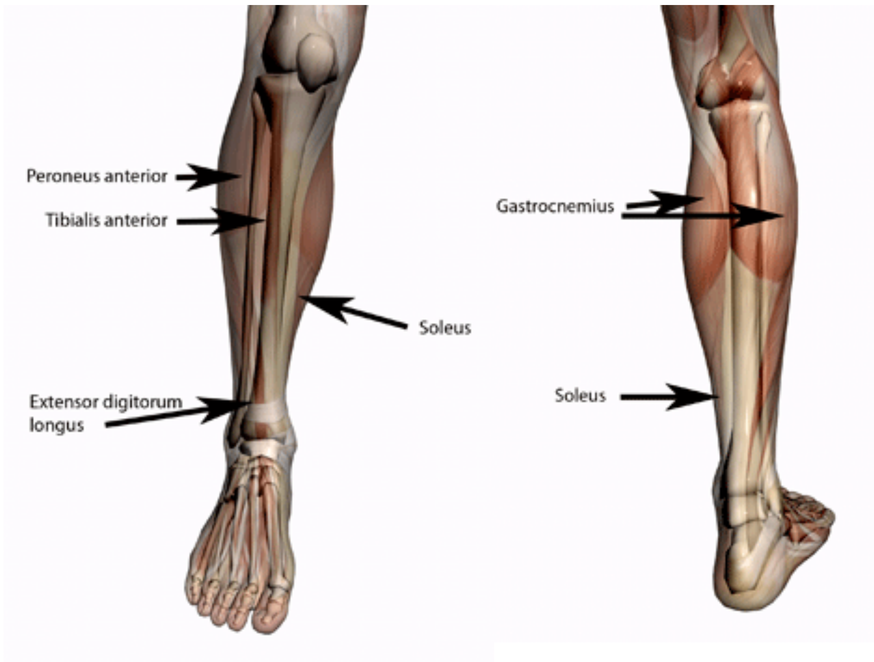
Kinematics of Running

- 1) Moment of Impact
- 2) Impact to Flat Foot
- 3) Flat Foot to Midstance
- 4) Midstance to Lift-off

Leg Muscles

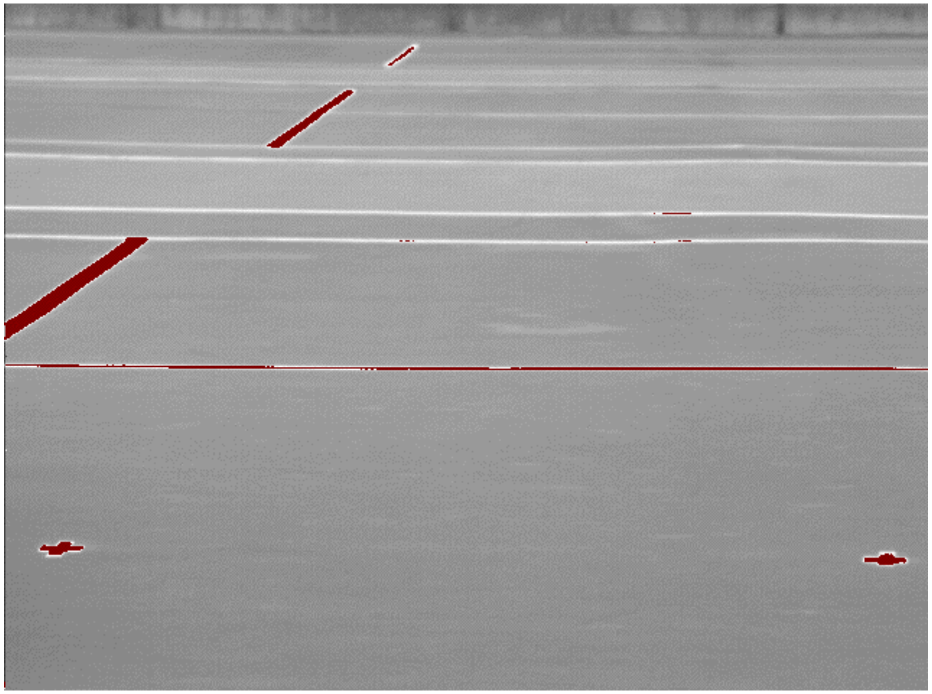


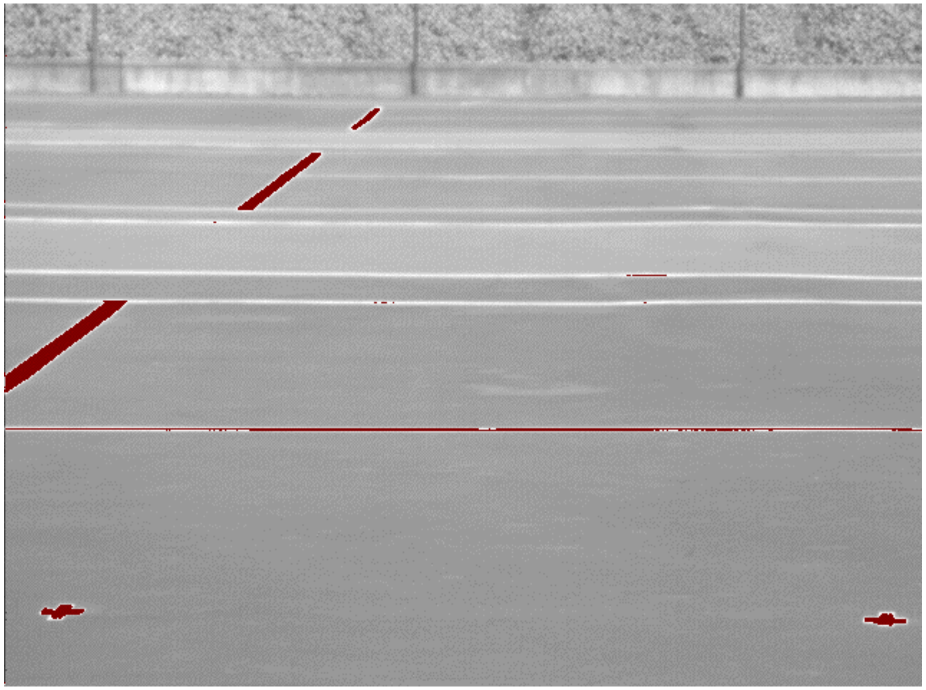
Whole leg raised by contraction of this muscle
Whole leg pulled back by contraction of this muscle
Leg bent by contraction of this muscle
Leg straightened by contraction of this muscle
Heel raised by contraction of this muscle
Toes raised by contracion of this muscle
Foot pushes against ground
Arch support



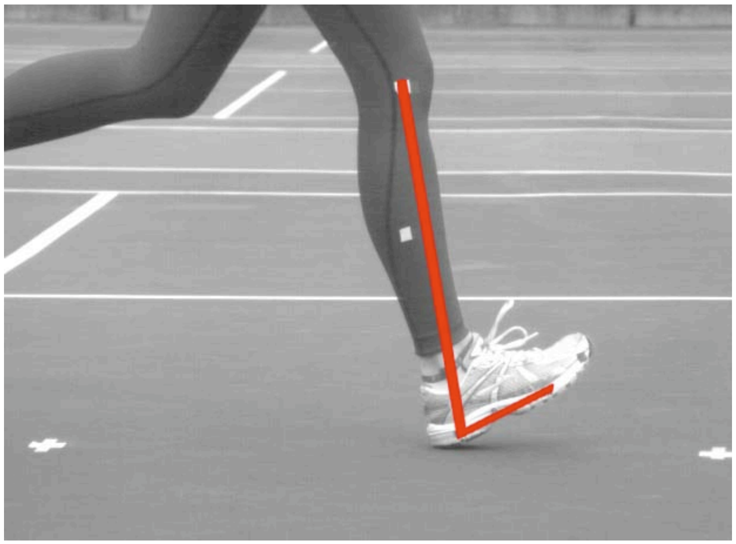
Peroneus anterior
Tibialis anterior
Soleus
Extensor digitorum longus
Gastrocnemius
Soleus

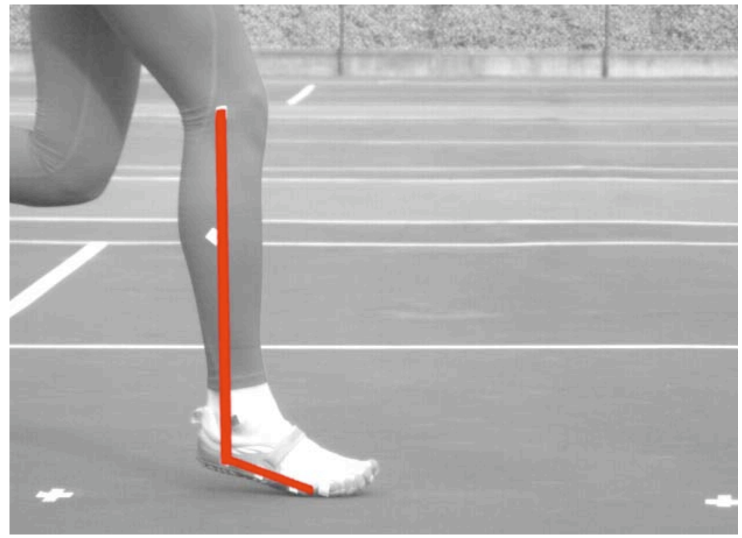
Sneakers vs. Five Fingers





1) Moment of Impact

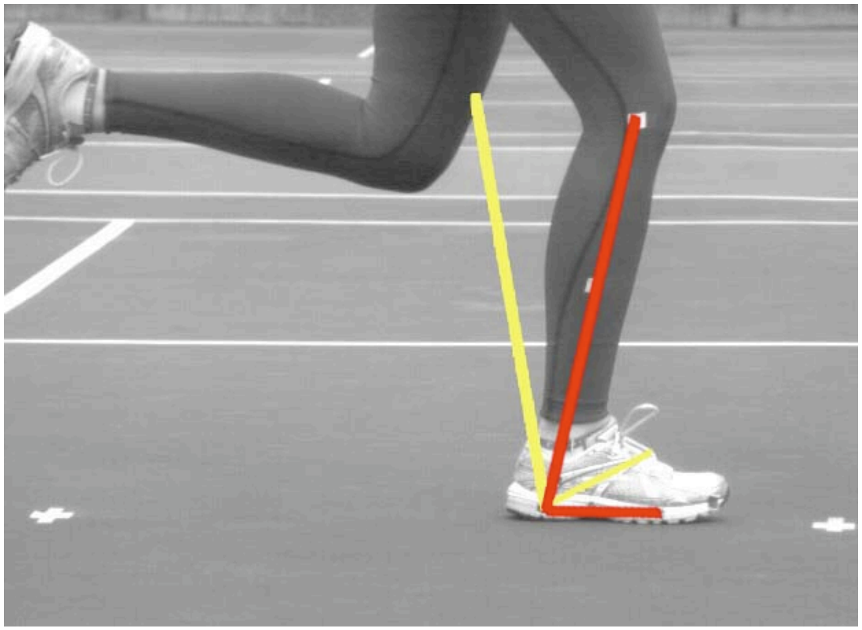


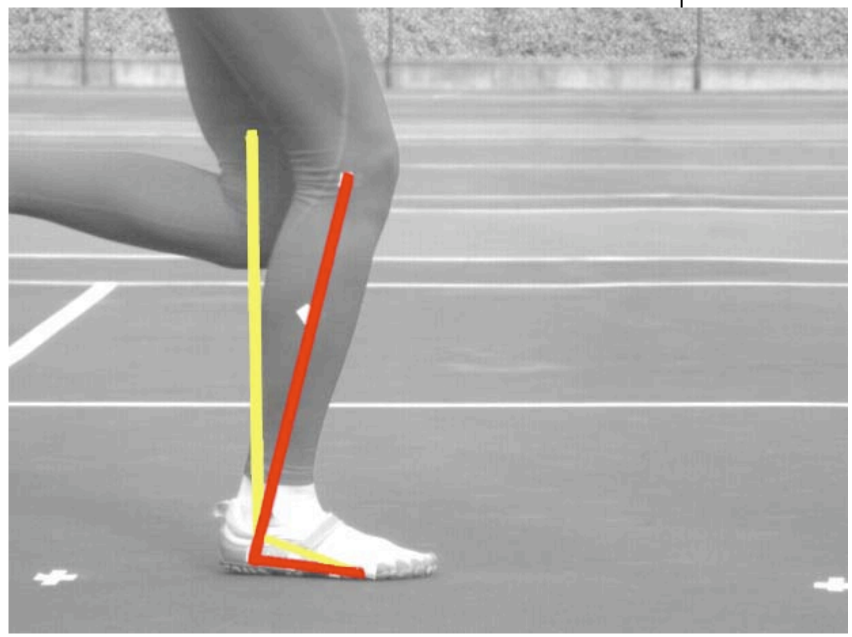


- Ankle is dorsiflexed
- Point of impact = rear of shoe
- Arch is not loaded

- Ankle is plantarflexed
- Point of impact = ball of foot
- Arch is loaded for support

2) Impact to Flat Foot

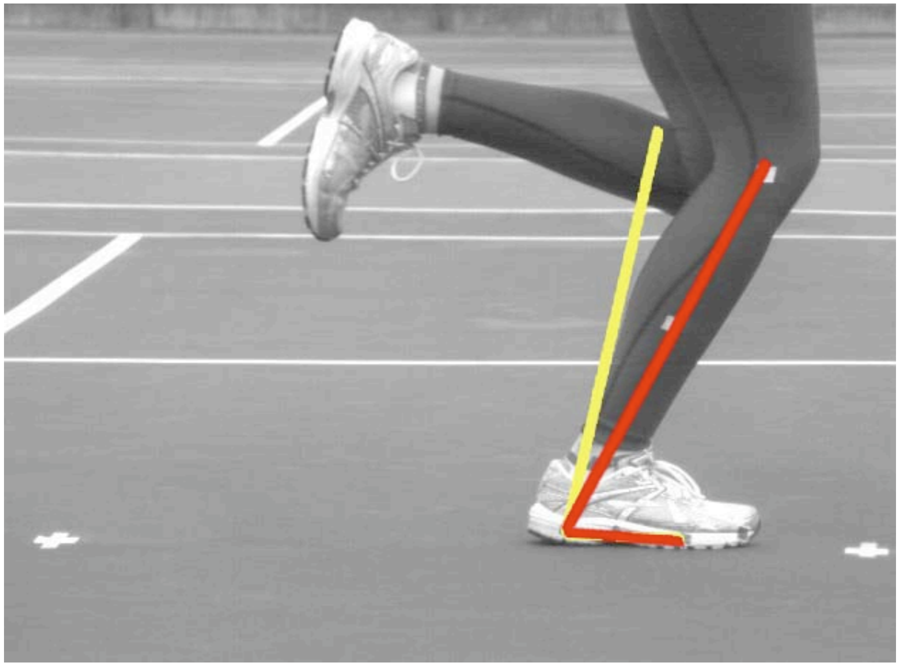




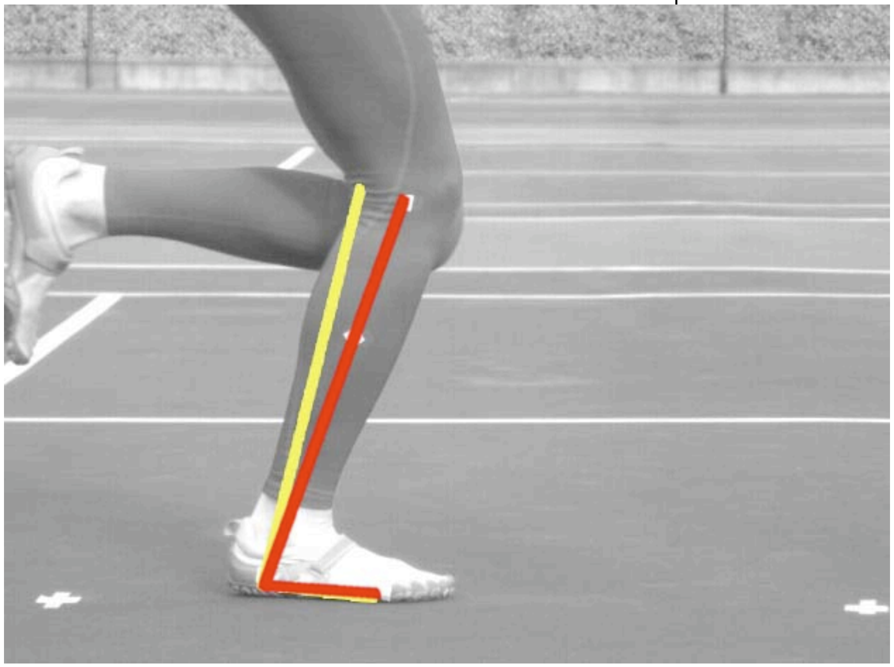
- Ankle position stays relatively constant

- Ankle dorsiflexes
- Arch stretches and begins to flatten
- Calf muscles and Achilles tendon stretch

3) Flat Foot to Midstance

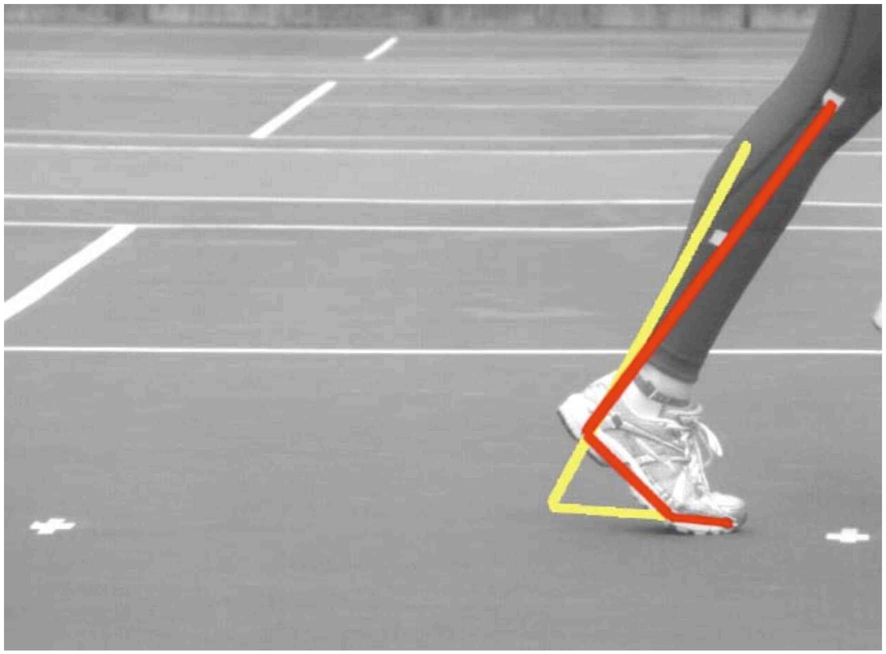


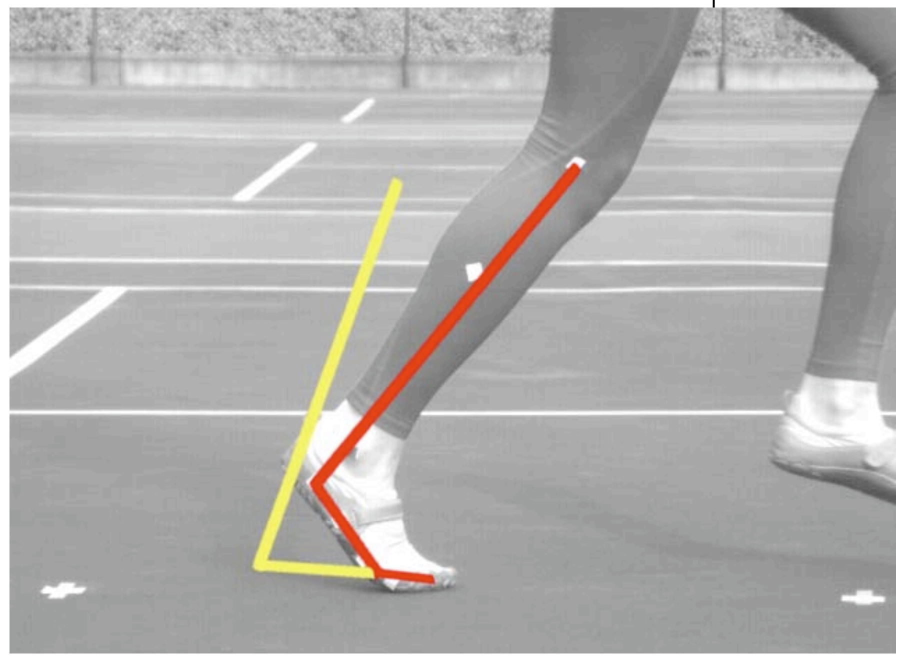
- Ankle dorsiflexes
- Arch *begins* to flatten and stretch slightly



- Ankle dorsiflexes
- Arch *continues* to stretch and flatten

4) Midstance to Lift-Off





- Ankle plantarflexes
- Arch recoils
- Toes flex

Momentum

- Inelastic collision = momentum is not conserved
- Heel-strike: vertical momentum is mostly absorbed by the collision force
- Forefoot-strike: some vertical momentum is converted into angular momentum as the majority of the mass continues to rotate

- Linear momentum: $p=mv$
- Angular momentum: $L = I\omega = I \times v/r$
  - I = moment of inertia, ω = angular momentum

Energy

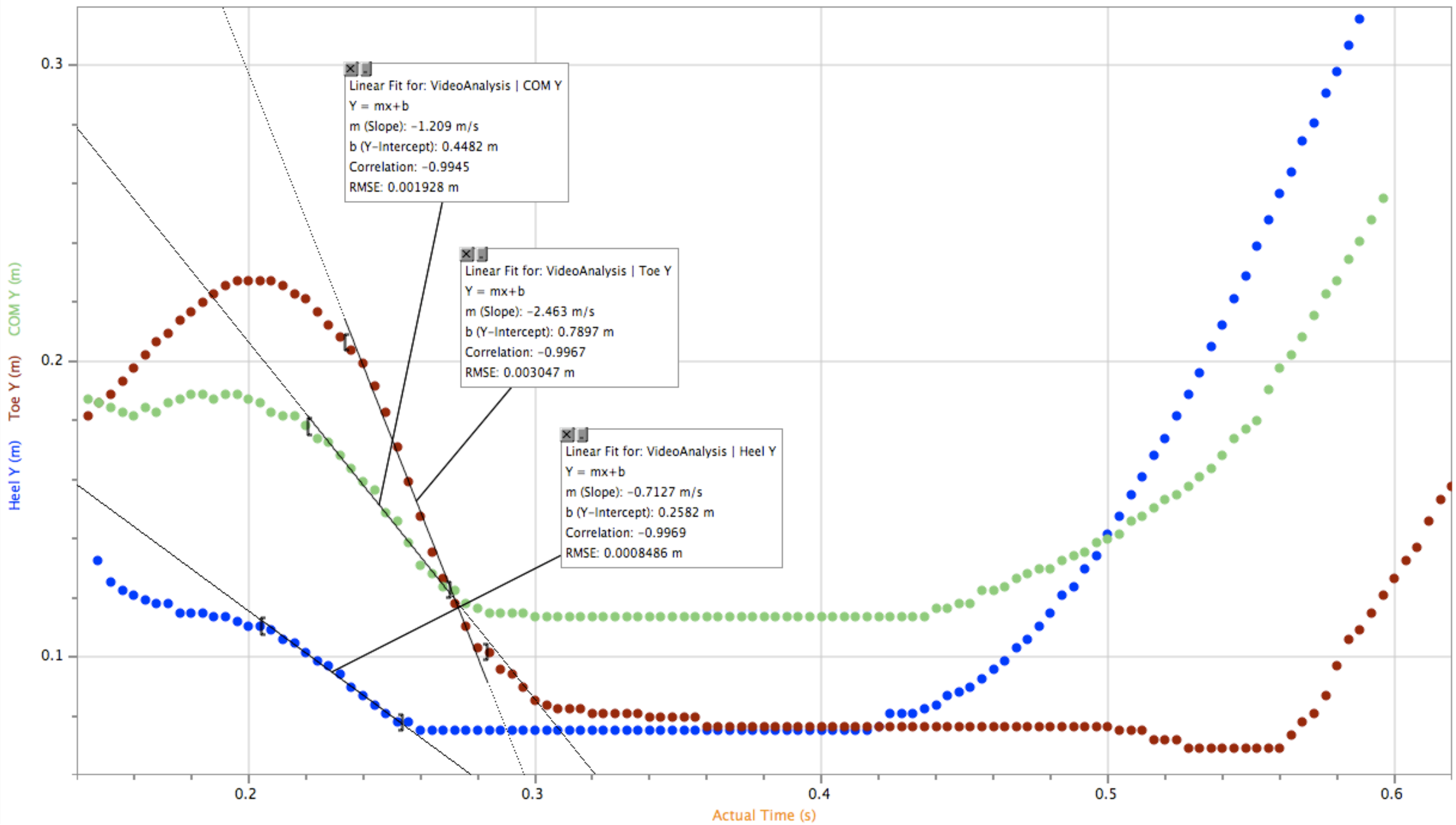
- Energy is not conserved
- Lift-off velocities are all larger than just before landing - energy is supplied by the leg muscles
- Evidence suggests that tendons and ligaments can store some kinetic energy as potential energy
  - Forefoot-striking may utilize the arch and Achilles tendon for spring loading on landing
  - Heel-striking does not appear to stretch tendons until midstance

Force and Impulse

$$\int_{0^-}^{T} F_z(t) = M_{\text{body}}(\Delta v_{\text{com}} + gT) = M_{\text{eff}}(-v_{\text{foot}} + gT)$$

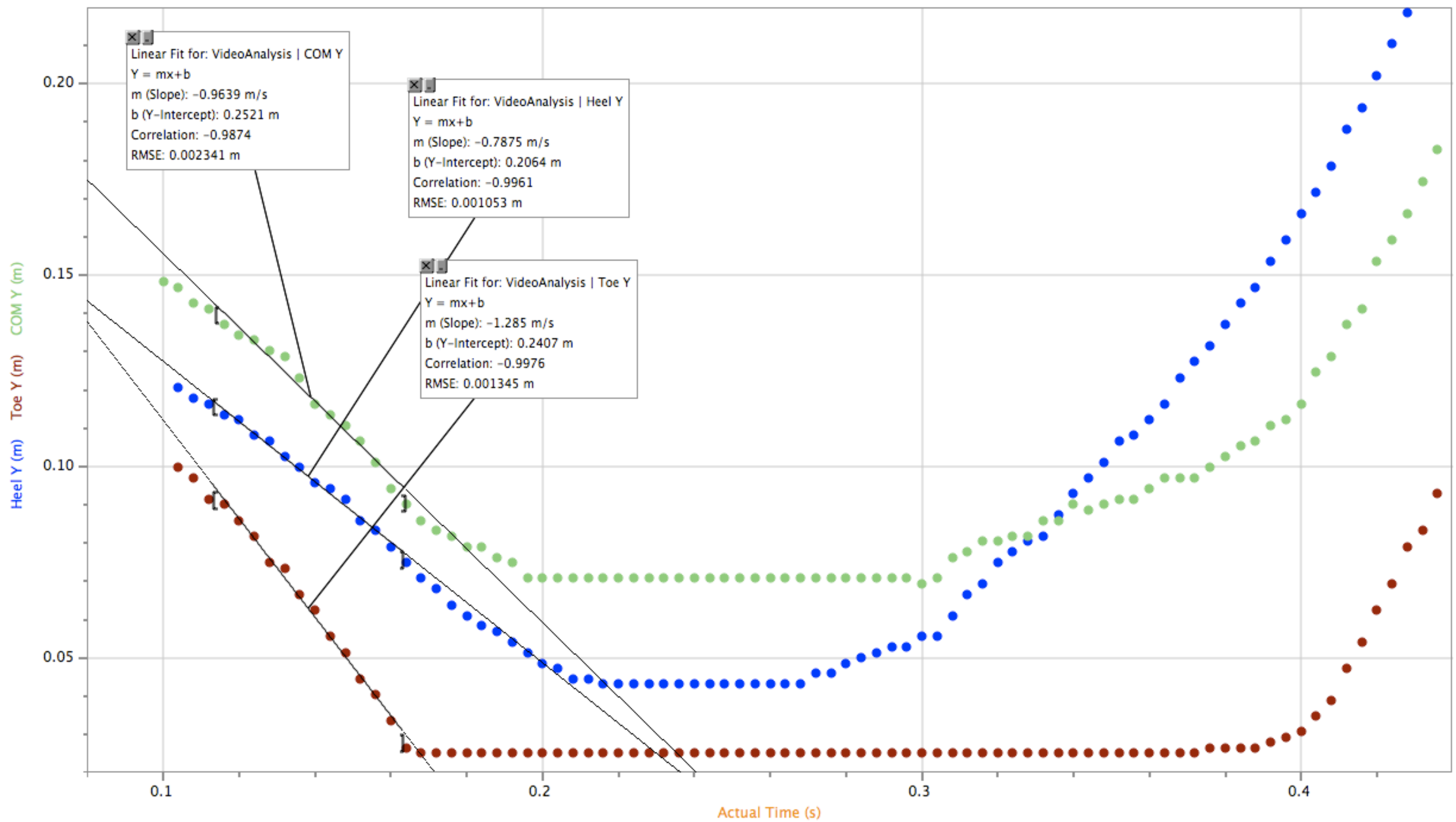
- M_{eff} = "effective mass" = portion of the body stopping abruptly on landing
  - Heel-strike = foot + lower leg = 6.8% body mass
  - Forefoot-strike = forefoot + some rearfoot + some leg = 1.7% body mass
- T = impact time
- v_{foot} = velocity of foot
- g = acceleration due to gravity = 9.81 m/s^2

Heel-Strike



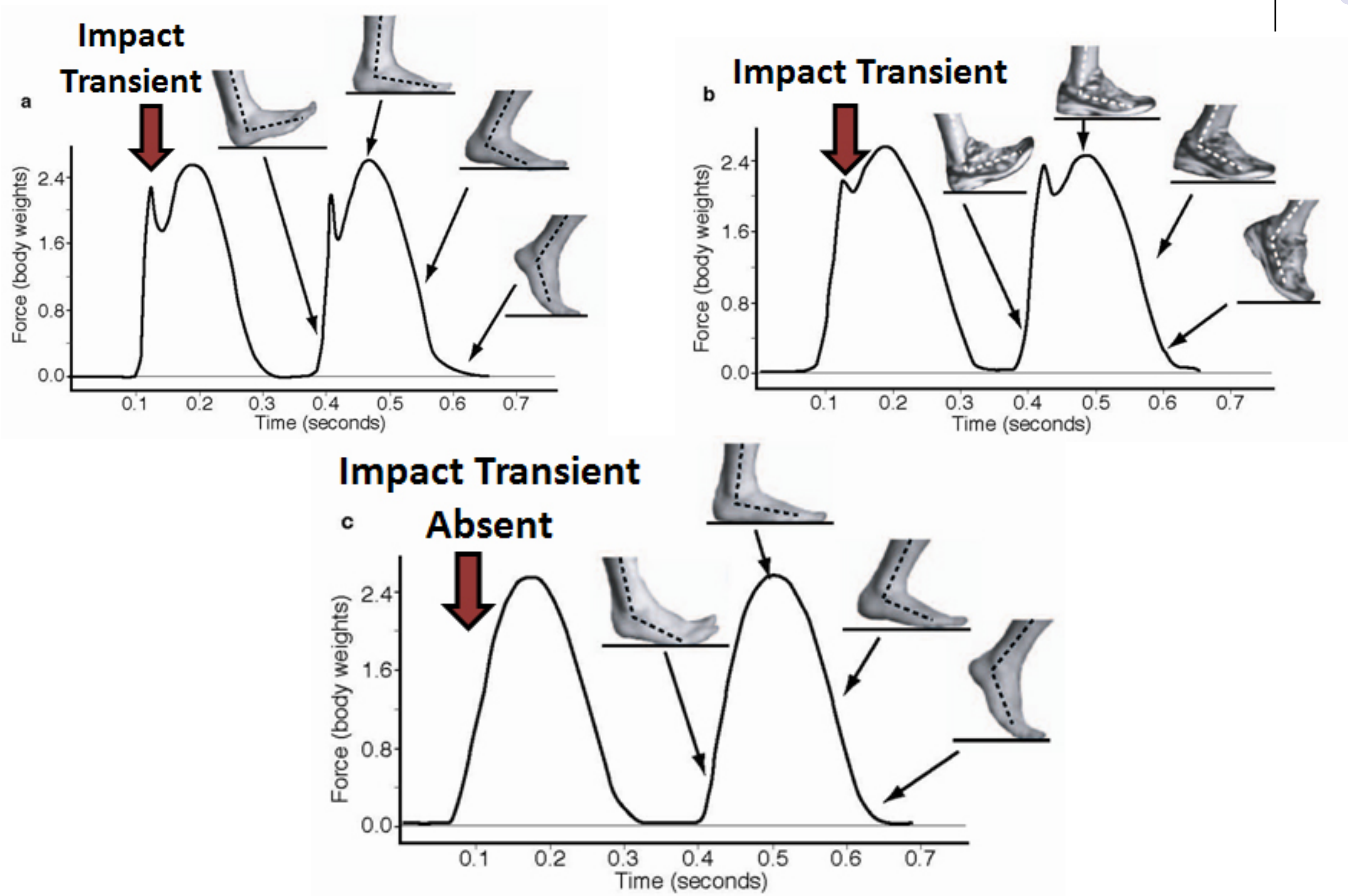
- Impulse = (0.068x64)[1.209+(9.81)(0.05)] = **7.40 N*s**
- Force = J/Δt = 7.40/0.05 = **147.92 N**

Forefoot-Strike



- Impulse = (0.017x64)[0.964+(9.81)(0.05)] = **1.58 N*s**
- Force = J/Δt = 1.58/0.05 = **31.64 N**

Impact Transient

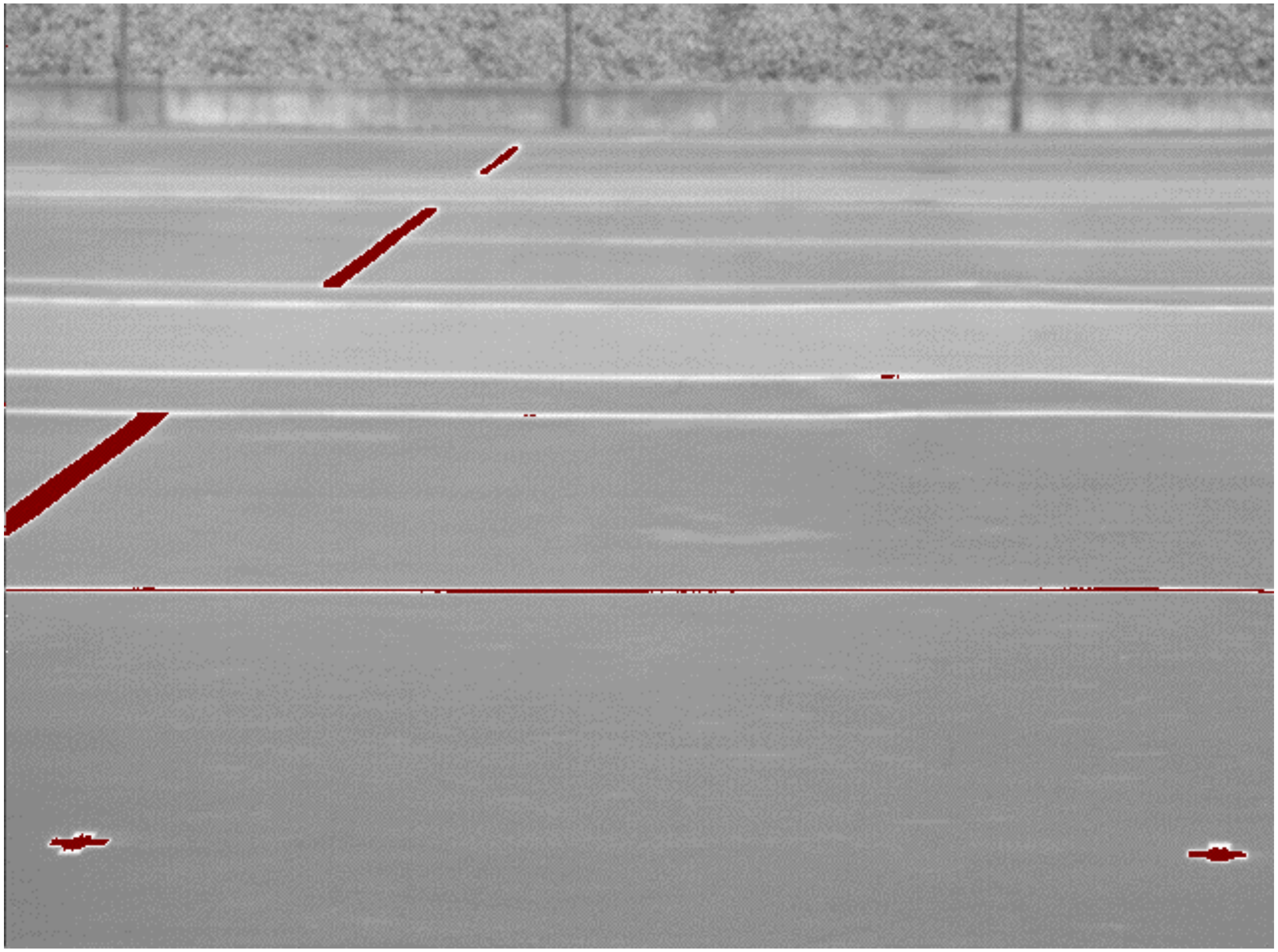


Putting it Together

	Heel-strike	Forefoot-strike
Effective mass	Foot + lower leg = 6.8% total body mass	Forefoot + some rearfoot and leg = 1.7% total body mass
Vertical Momentum	Absorbed by collision	Converted into rotational momentum
Spring-loading	No	Yes
Impact force in 5 ms	147.92 N	31.64 N
Total force	F=ma (same)	F=ma (same)
Impact transient	Present, reduced by cushioned sneakers	Absent!

Training

- Forefoot striking feels unnatural to most runners used to highly supportive footwear
- Individuals who learn to run without footwear tend to naturally forefoot-strike
- Training barefoot (or with “Five Fingers”) and wearing minimalist footwear with less support can encourage forefoot striking even in sneakers



Conclusions

- Decreasing the effective mass on landing reduces the immediate force of impact (0.05 s)
- Supportive sneakers decrease the impact transient when heel-striking but not to the extent of a forefoot strike
- Loading of the arch tendons may store kinetic energy as potential energy for take-off during a forefoot strike
- Training barefoot can strengthen the muscles needed for running with a forefoot strike while wearing sneakers

- Further questions
  - How much potential energy is actually stored in the arch?
  - How do impact forces correlate with injury?
  - How much linear momentum is converted to angular momentum?

Sources

- Lieberman, Daniel E. et al. (2010) Foot Strike Patterns and Collision Forces in Habitually Barefoot versus Shod Runners. *Nature* 463.10: 531-35.
- Lieberman, Daniel E., Madhusudhan Venkadesan, Adam I. Daoud, and William A. Werbel. "Biomechanics of Foot Strikes and Applications to Running Barefoot or in Minimal Footwear." *Running Barefoot*. Harvard University. Web. 07 Apr. 2011. <http://barefootrunning.fas.harvard.edu/>.
- Bramble, D. M. and Lieberman, Daniel E (2004) Endurance running and the Evolution of Homo. *Nature*. 432: 345-352
- Van Gent, R. N., Siem, D., and van Middelkoop, M. et al. (2007) Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *Br J Sports Med* 41: 469-480