

Effects of Aerobic Exercise on the Knee, a Biomechanics & MRI Perspective

Anthony Gatti

March 11, 2020

York University - KINE 4470 Muscle and Joint Biomechanics

Overview

- Osteoarthritis & Cartilage
- Cartilage & MRI
- Cumulative Load
- Effect of Equal Cumulative Load of Running & Bicycling on Cartilage
- Knee Joint Reaction Forces
- Effect of Bicycle-Fit on Knee Joint Reaction Forces
- Future work

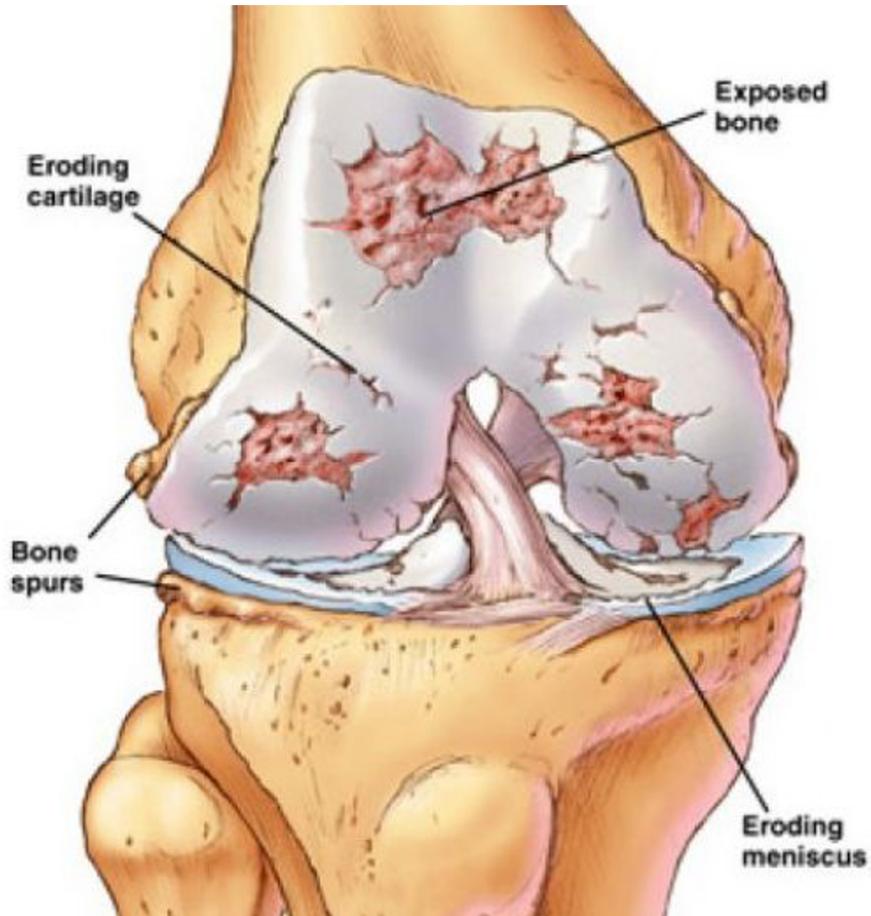
Osteoarthritis & Cartilage

Joint Health & Osteoarthritis (OA)



- Osteoarthritis affect 50% of people over 65
 - 80% of people over 75
- Cost the Canadian economy > \$25-billion in 2010
 - Projected to increase due to aging population

What is Osteoarthritis



Retrieved from <http://www.orthobethesda.com/education/osteoarthritis.aspx>

Articular Cartilage Biology

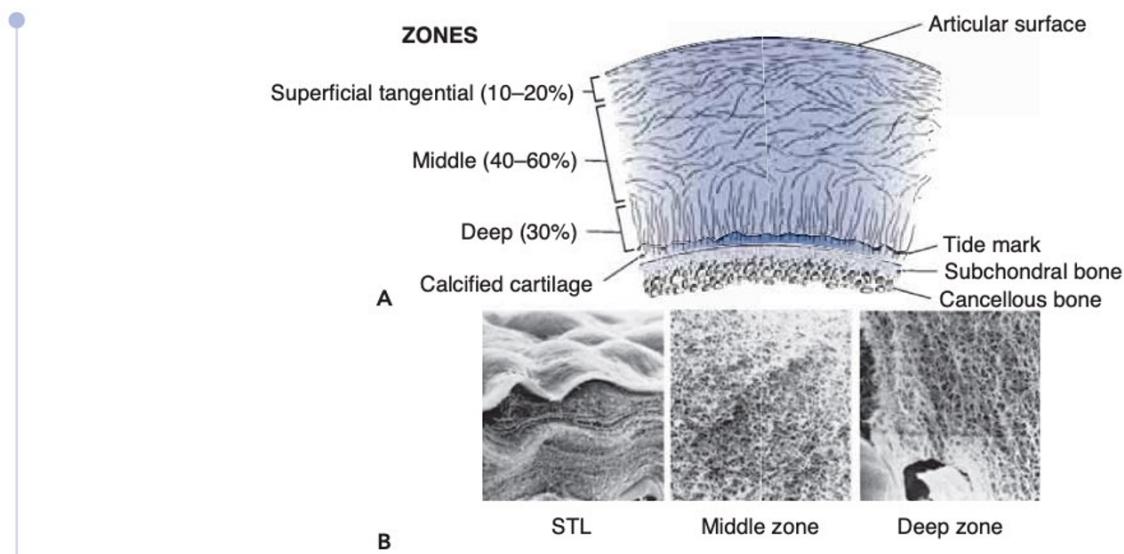


FIG. 3-3

A. Schematic representation. Reprinted with permission from Mow, V.C., Lai, W.M., Redler, I. (1974). Some surface characteristics of articular cartilages. A scanning electron microscopy study and a theoretical model for the dynamic interaction of synovial fluid and articular cartilage. *J Biomech*, 7, 449. B. Photomicrographs ($\times 3000$; courtesy of Dr. T. Takei, Nagano, Japan) of the ultrastructural arrangement of the collagen network throughout the depth of articular cartilage. In the superficial tangential zone (STZ), collagen fibrils are tightly woven into sheets arranged parallel to the articular

surface. In the middle zone, randomly arrayed fibrils are less densely packed to accommodate the high concentration of proteoglycans and water. The collagen fibrils of the deep zone form larger radially oriented fiber bundles that cross the tidemark, enter the calcified zone, and anchor the tissue to the underlying bone. Note the correspondence between this collagen fiber architecture and the spatial arrangement of the chondrocytes shown in Figure 3-1. In photomicrographs B, the STZ is shown under compressive loading while the middle and deep zones are unloaded.

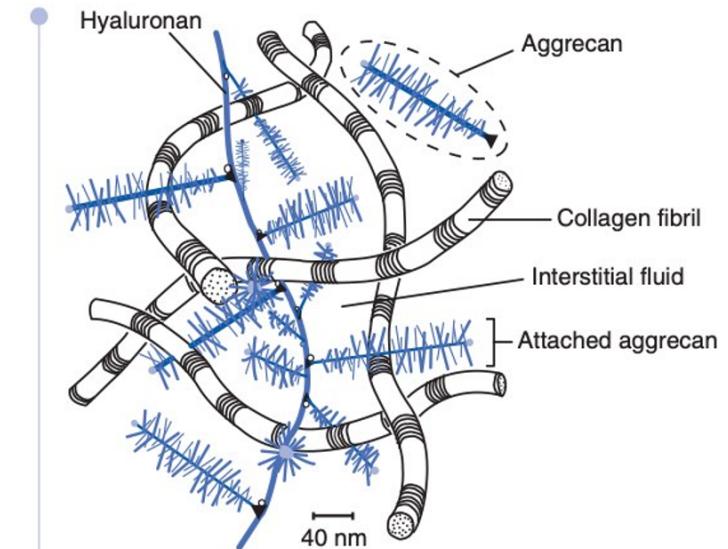


FIG. 3-8

Schematic representation of the molecular organization of cartilage. The structural components of cartilage, collagen, and proteoglycans interact to form a porous composite fiber-reinforced organic solid matrix that is swollen with water. Aggrecans bind covalently to HA to form large proteoglycan macromolecules.

Articular Cartilage Biology

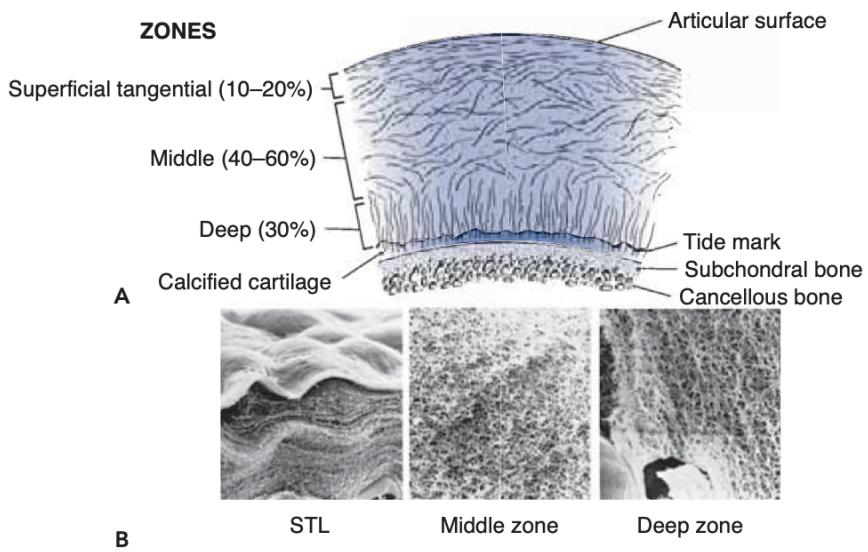
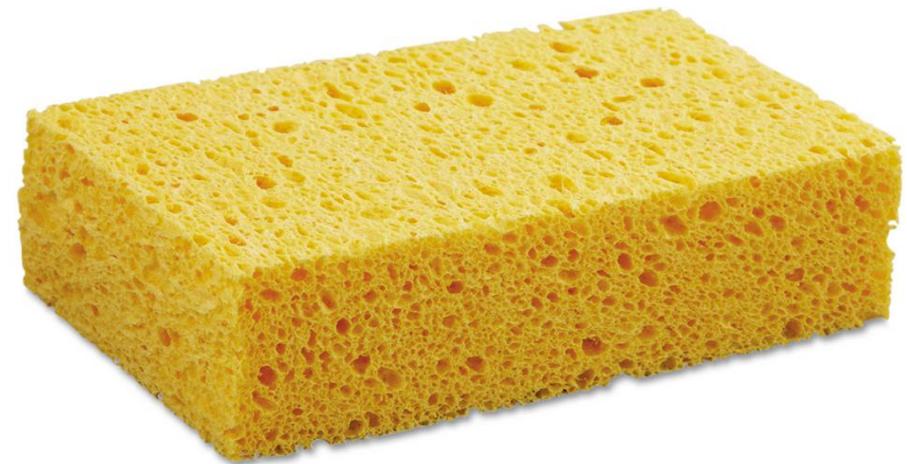


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Cartilage & MRI

Knee MRI - Cartilage

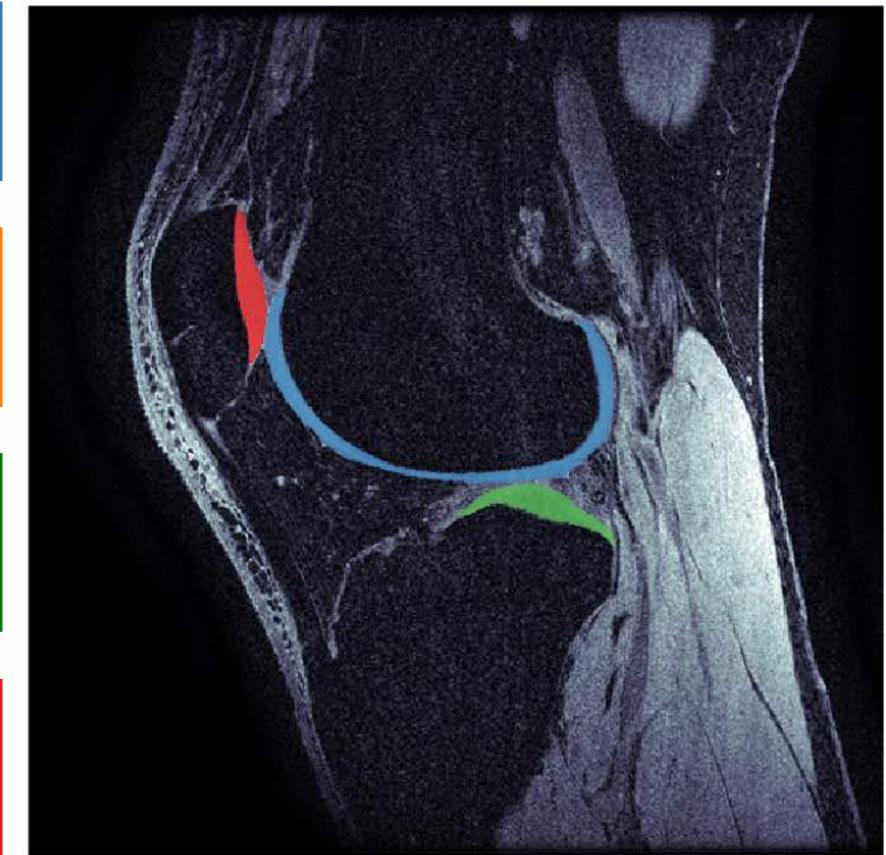


Femoral
Cartilage

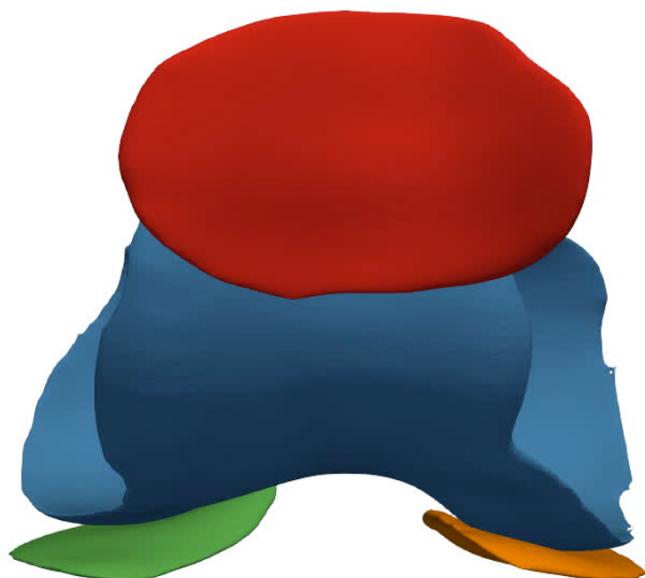
Medial Tibial
Cartilage

Lateral Tibial
Cartilage

Patellar
Cartilage



Knee MRI – Cartilage



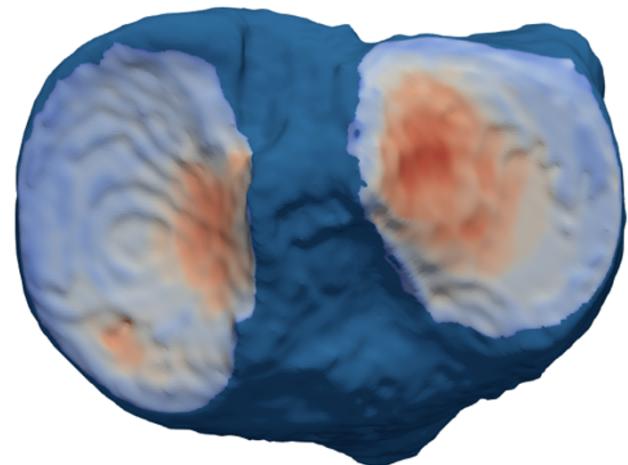
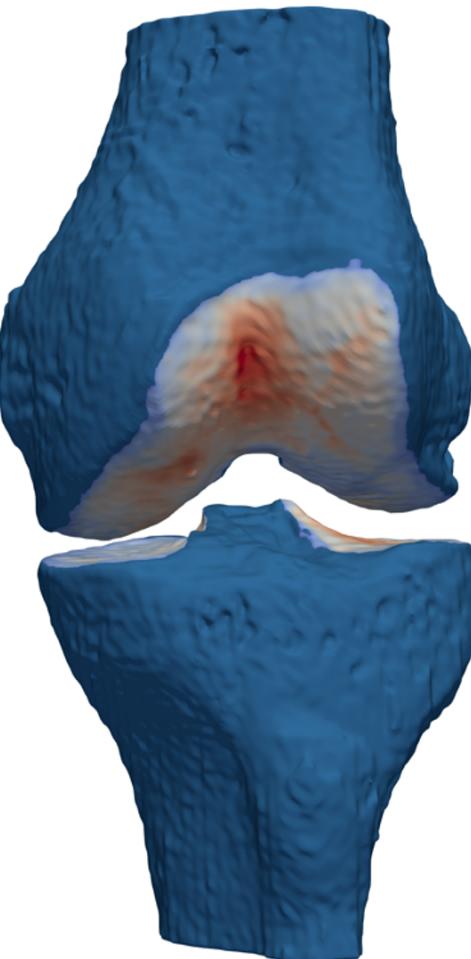
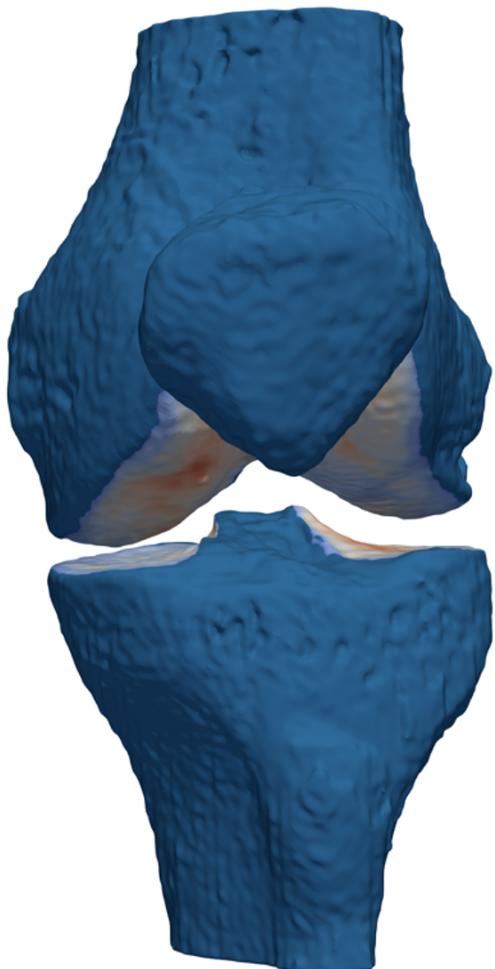
Femoral
Cartilage

Medial Tibial
Cartilage

Lateral Tibial
Cartilage

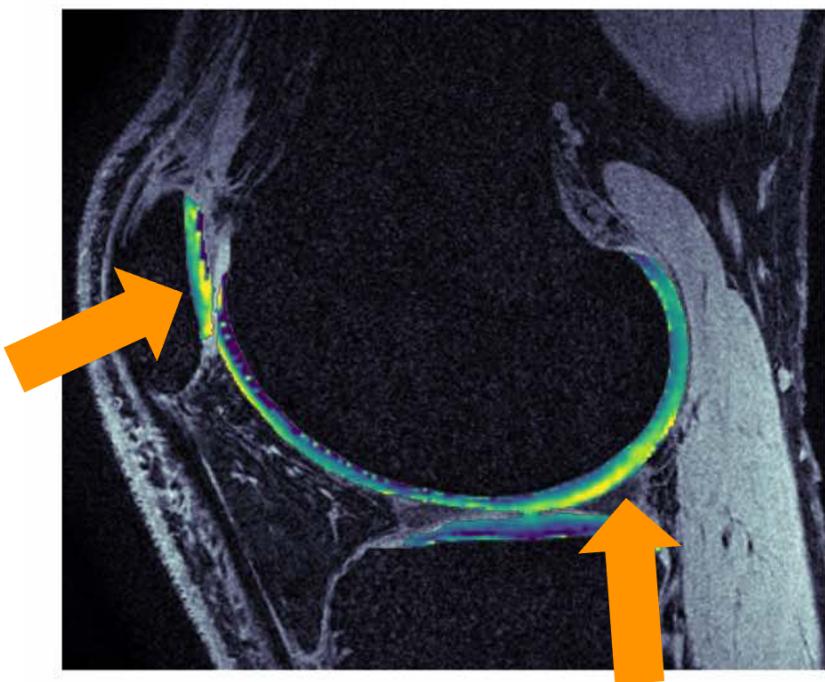
Patellar
Cartilage

Knee MRI – Cartilage

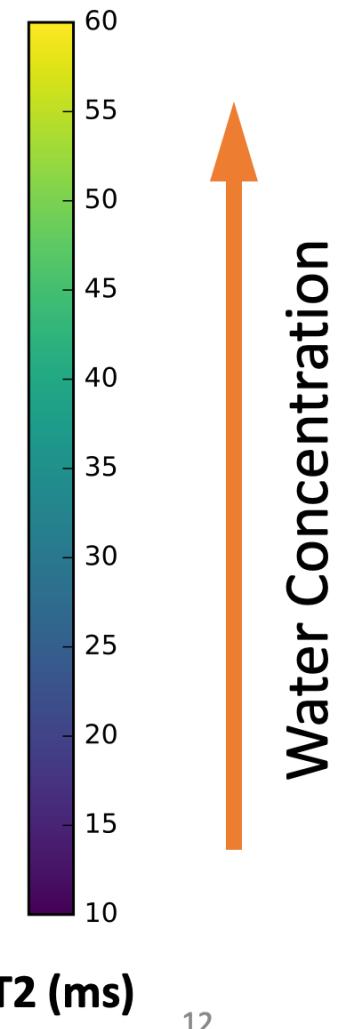


Knee MRI – Cartilage Hydration (T2)

Pre - Activity



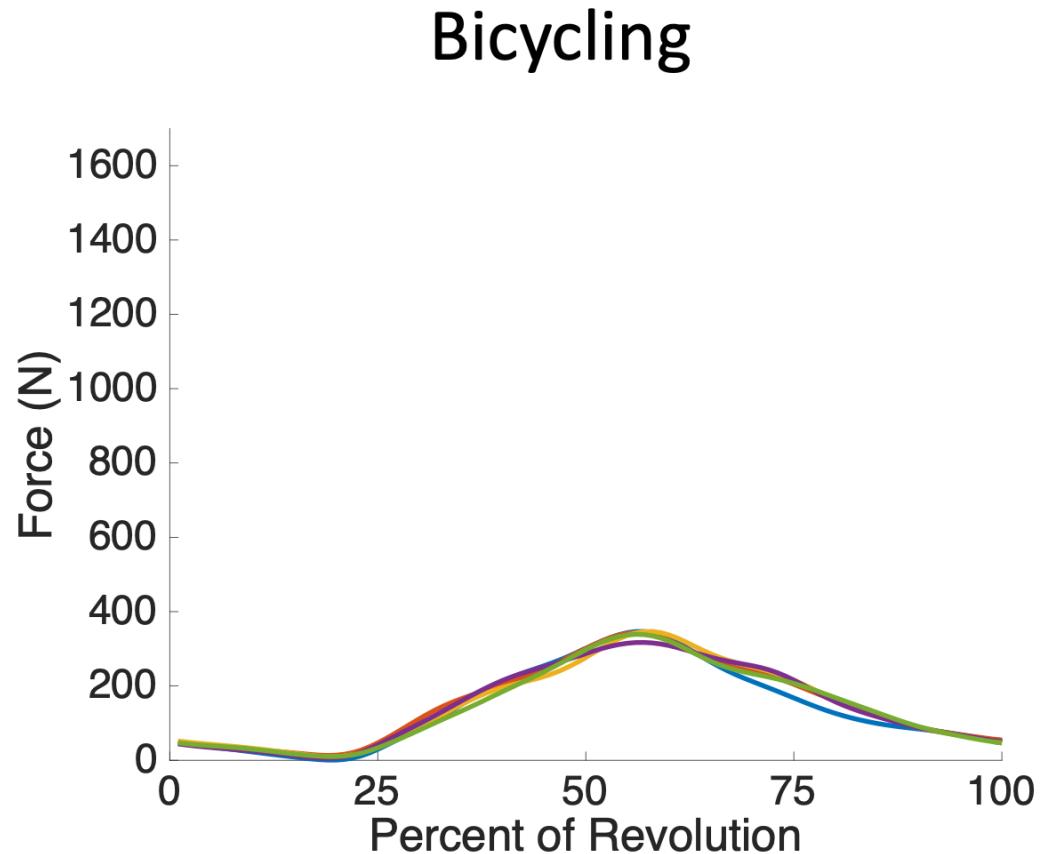
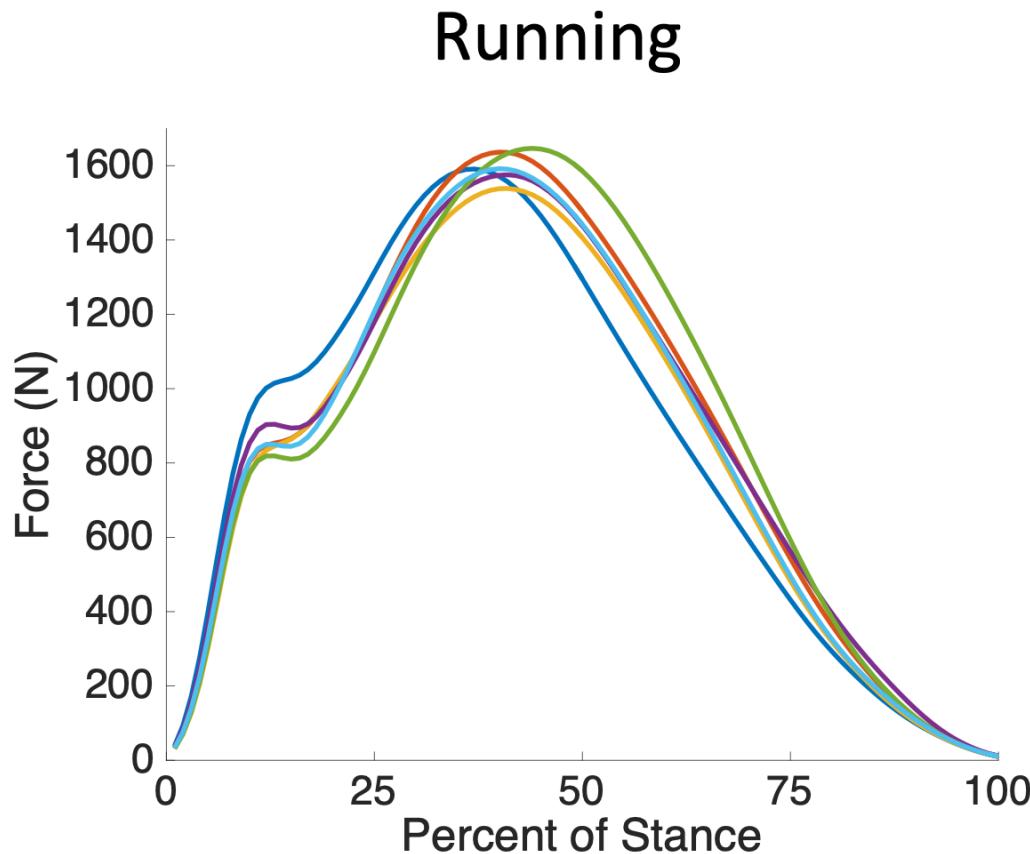
Post - Activity



Loading compresses cartilage & water content

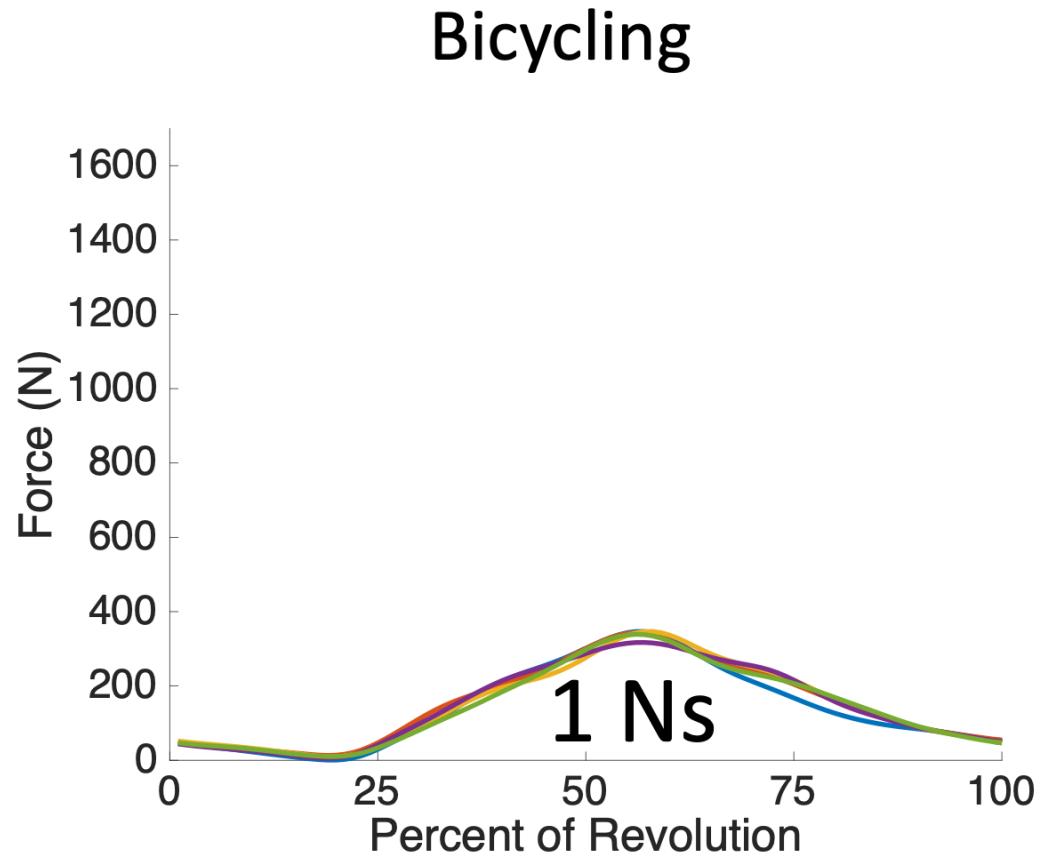
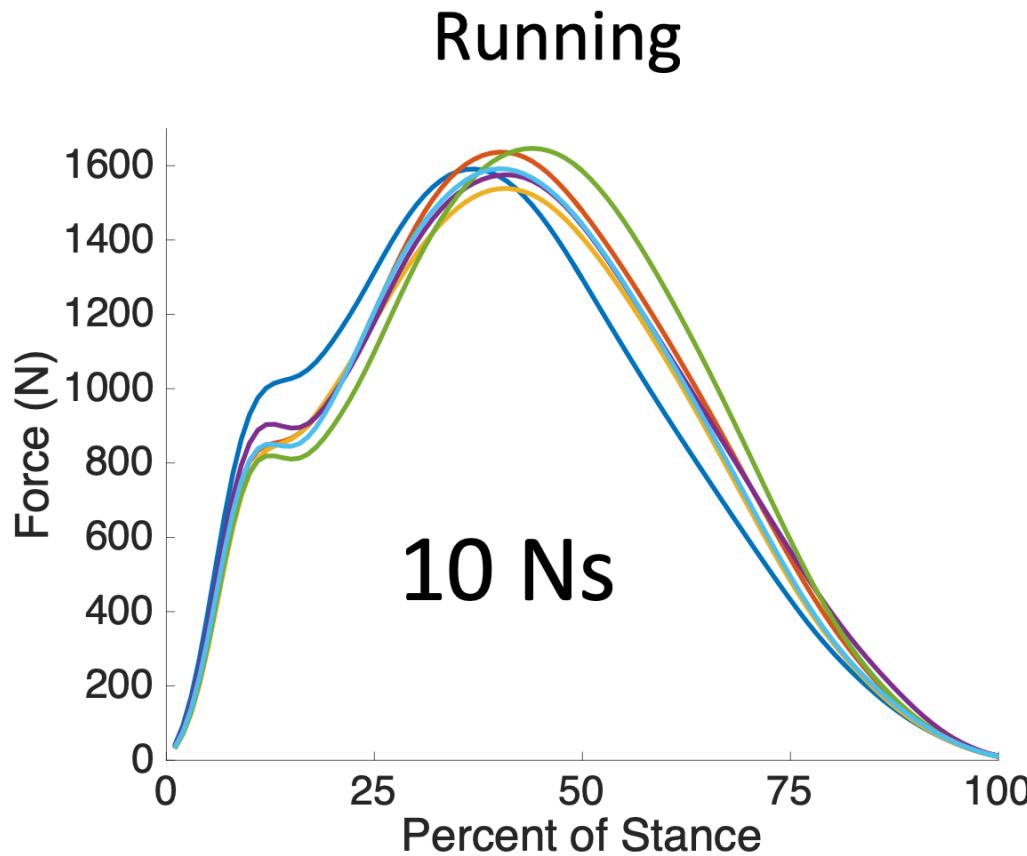
Cumulative Load

Cumulative Load @ the foot



Impulse ($N \cdot s$) = $\int F \, dt$; **Cumulative load** = impulse * loading repetition

Cumulative Load @ the foot



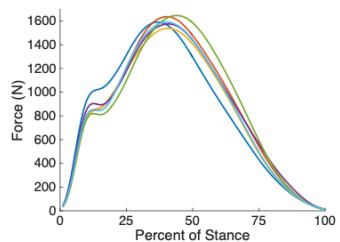
Impulse ($N \cdot s$) = $\int F \, dt$; Cumulative load = impulse * loading repetition [7]

Effect of Equal Cumulative Load
of Running & Bicycling
on Cartilage

Cartilage Δ in Running vs. Bicycling

Visit 1

Biomechanics Collection
Determine Impulse of step /
pedal revolution



Visit 2

MRI Bicycling
avg 45 minutes



Visit 3

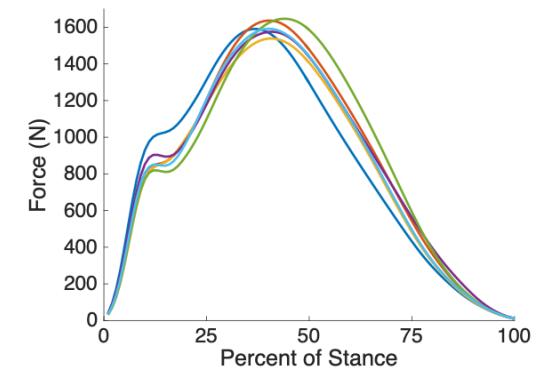
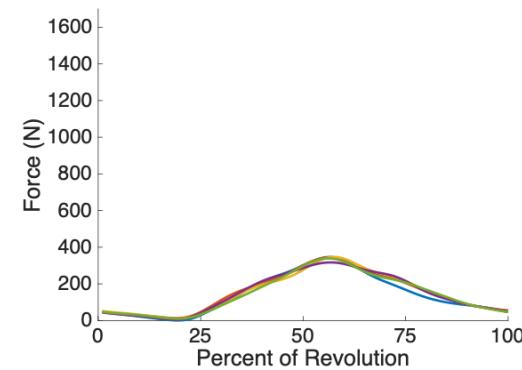
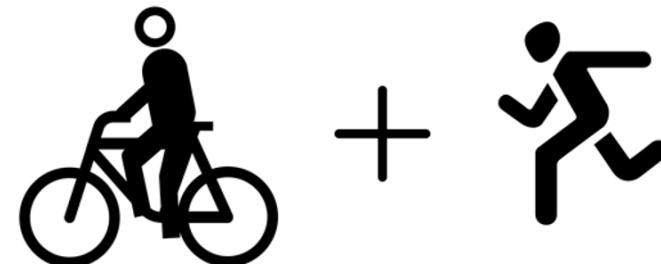
MRI Running
avg 15 minutes



Cartilage Δ in Running vs. Bicycling

Visit 1

Biomechanics Collection
Determine Impulses

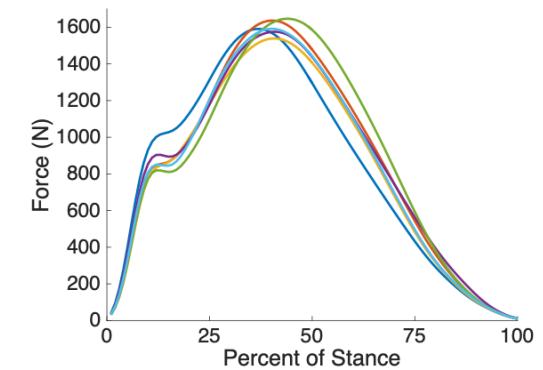
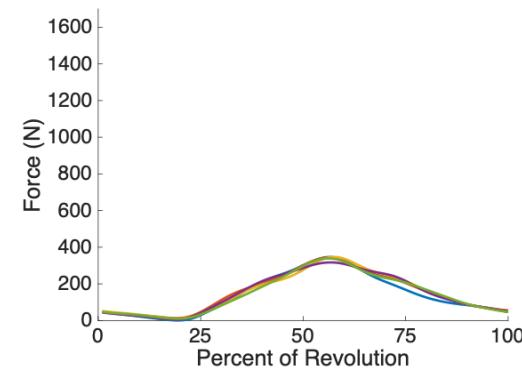
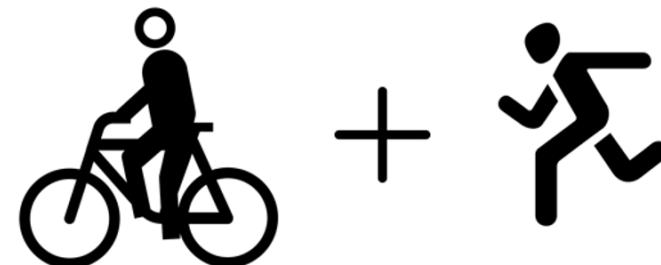


Cartilage Δ in Running vs. Bicycling

Visit 1

Biomechanics Collection
Determine Impulses

Steps / minute = Revs / minute

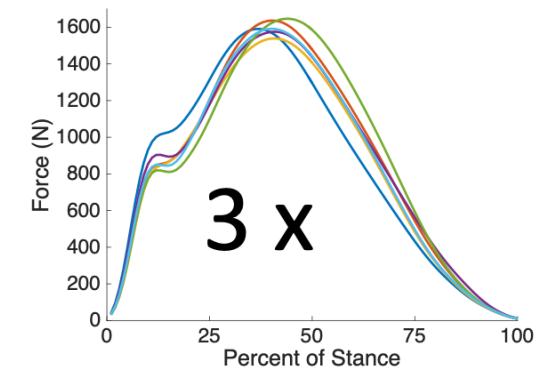
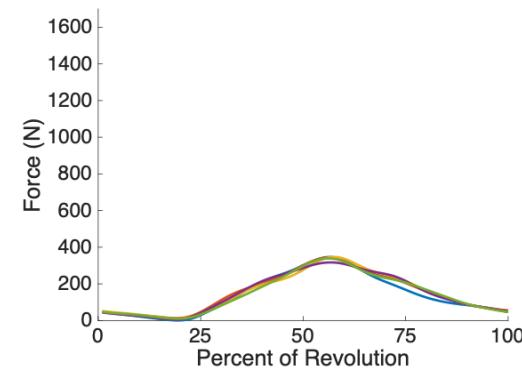
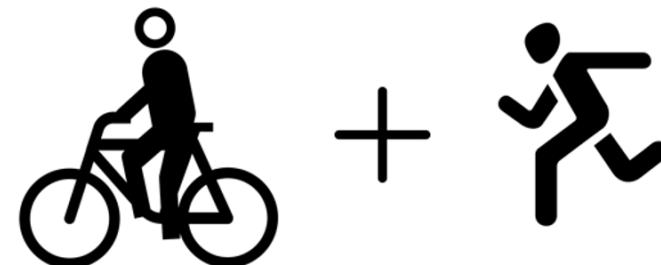


Cartilage Δ in Running vs. Bicycling

Visit 1

Biomechanics Collection
Determine Impulses

Steps / minute = Revs / minute
Step impulse = 3 x Pedal impulse



Cartilage Δ in Running vs. Bicycling

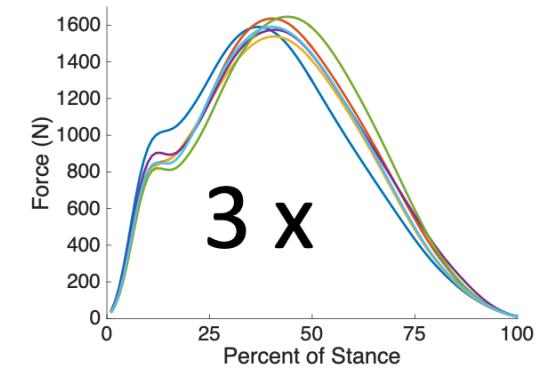
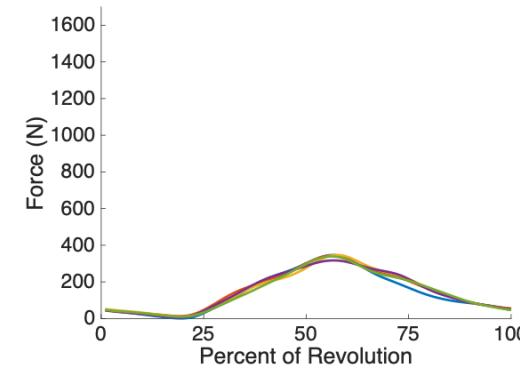
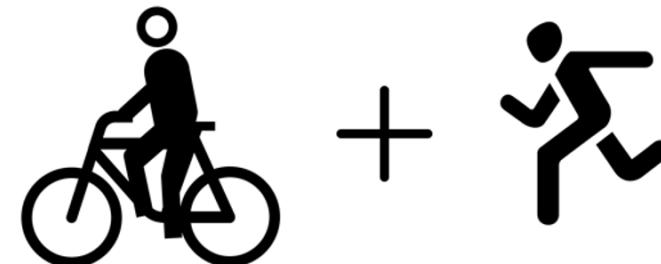
Visit 1

Biomechanics Collection
Determine Impulses

Steps / minute = Revs / minute

Step impulse = 3 x Pedal impulse

To achieve equal cumulative load, bicycling is 3 x longer than running



Cartilage Δ in Running vs. Bicycling

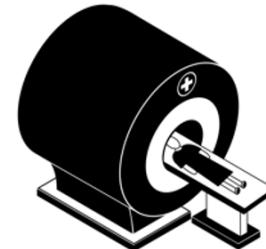
Visit 2

MRI Bicycling
avg 45 minutes

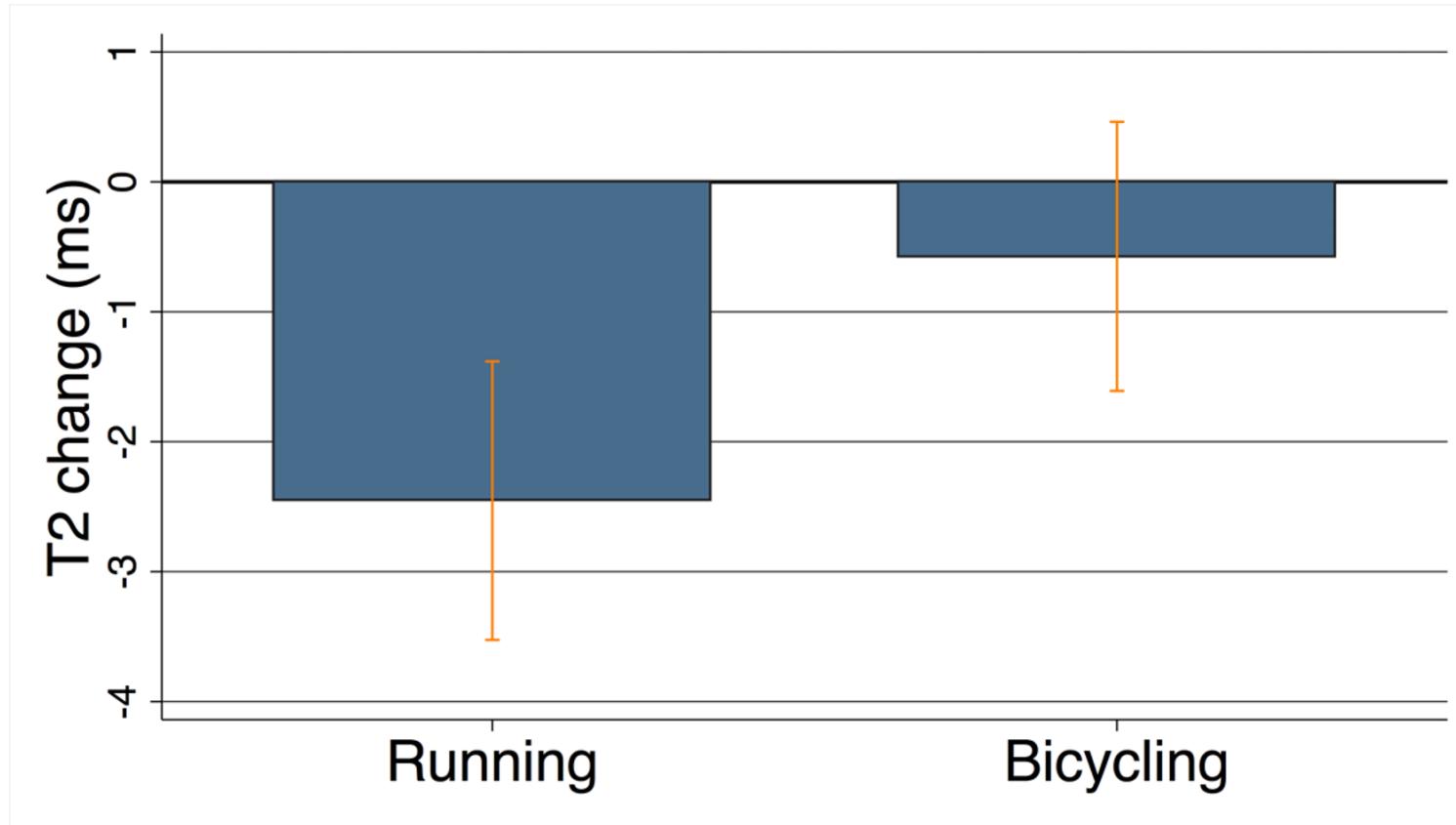


Visit 3

MRI Running
avg 15 minutes



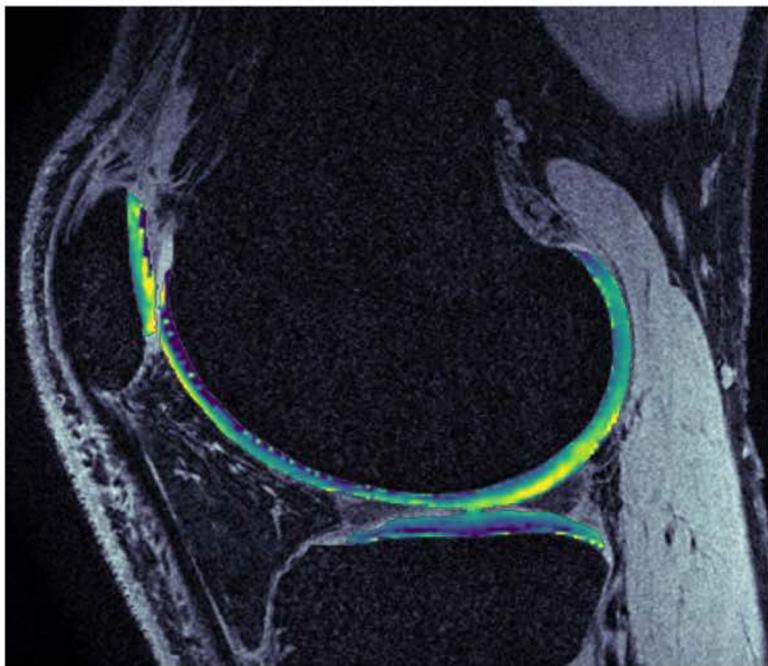
Results – Acute Changes in Cartilage T2



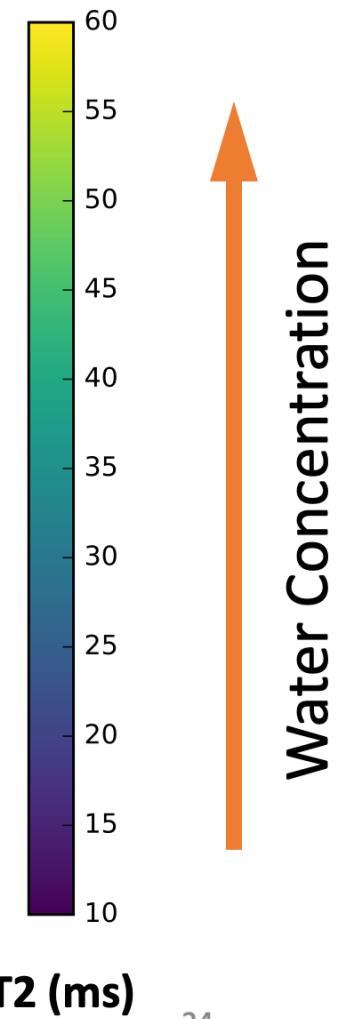
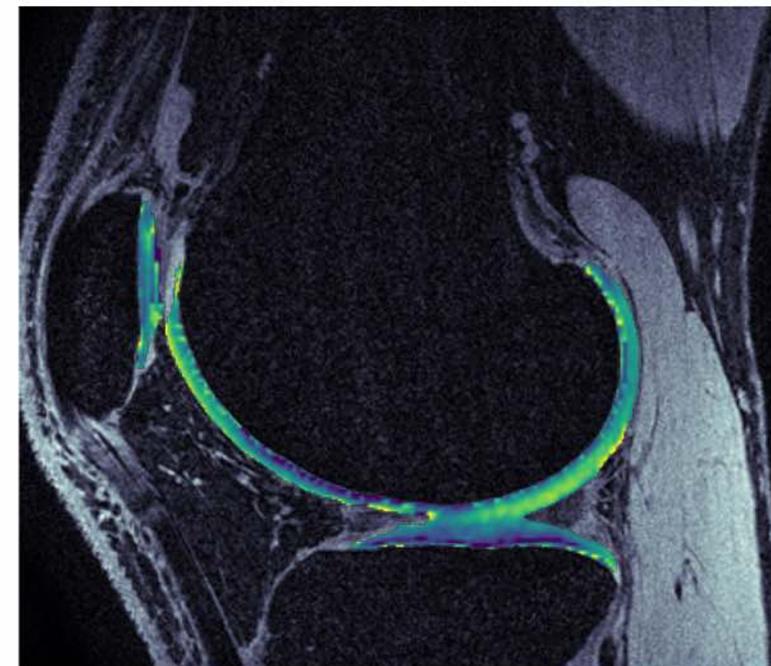
Running shortened T2, bicycling did not

Knee MRI – Cartilage Hydration (T2)

Pre - Activity



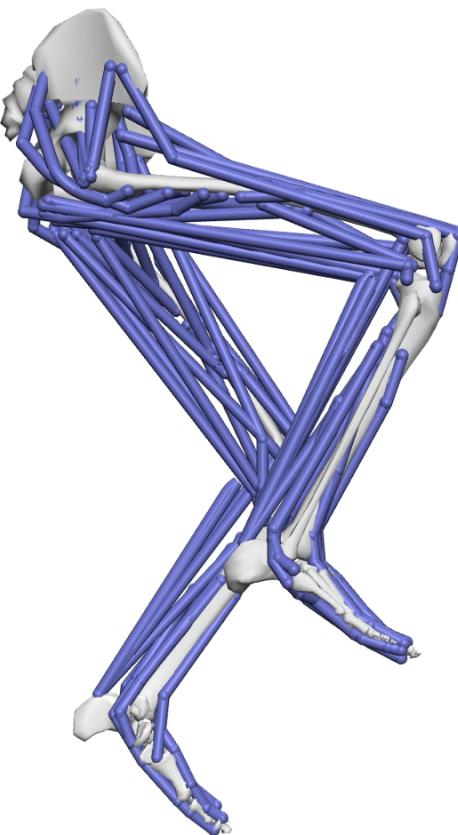
Post - Activity



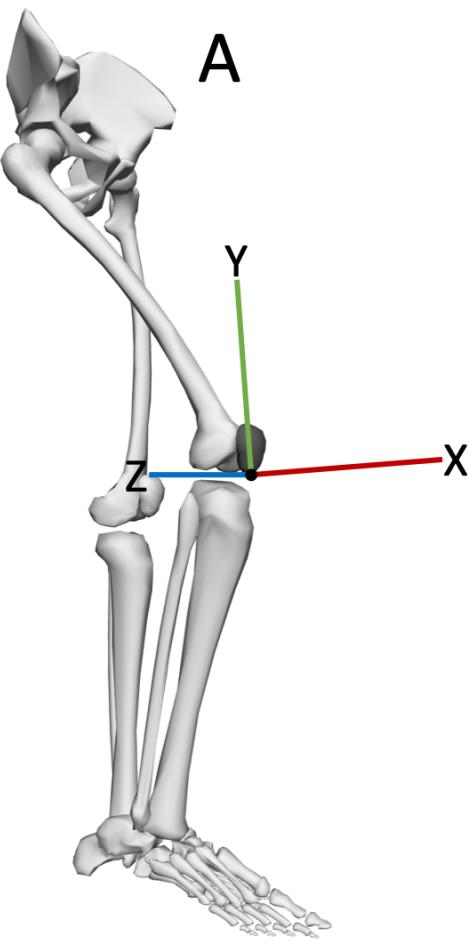
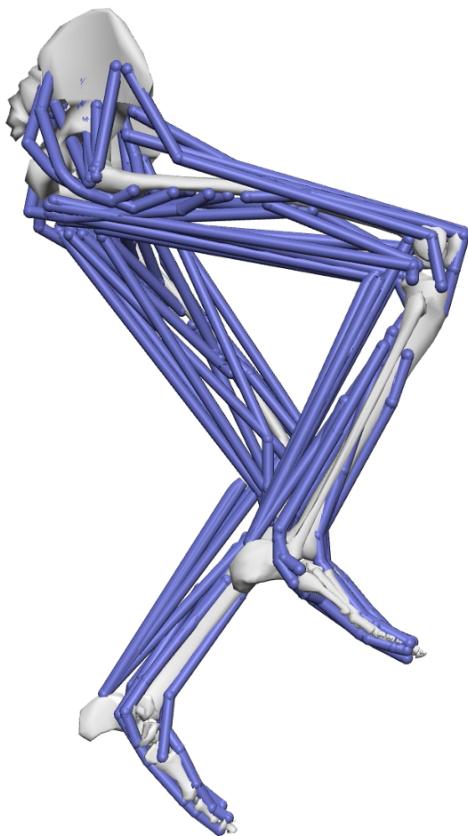
Loading compresses cartilage & water content^[4,5,6]

Knee Joint Reaction Forces

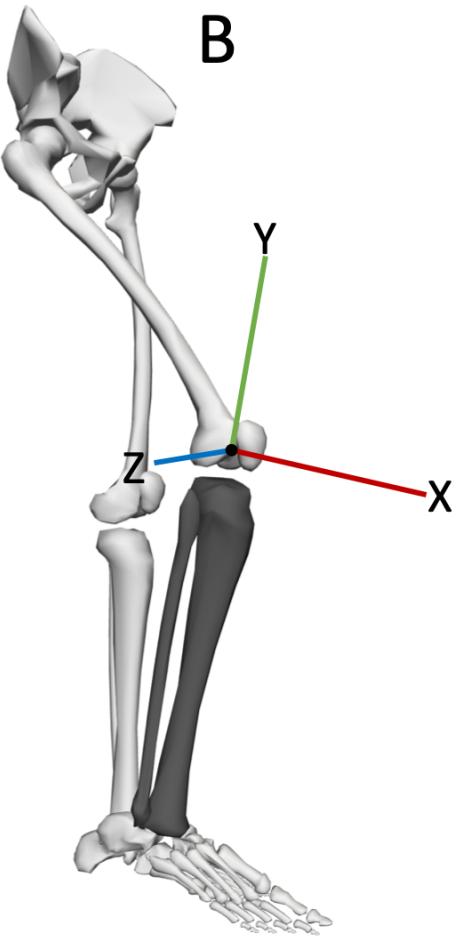
Musculoskeletal Model



Musculoskeletal Model - Coordinate System

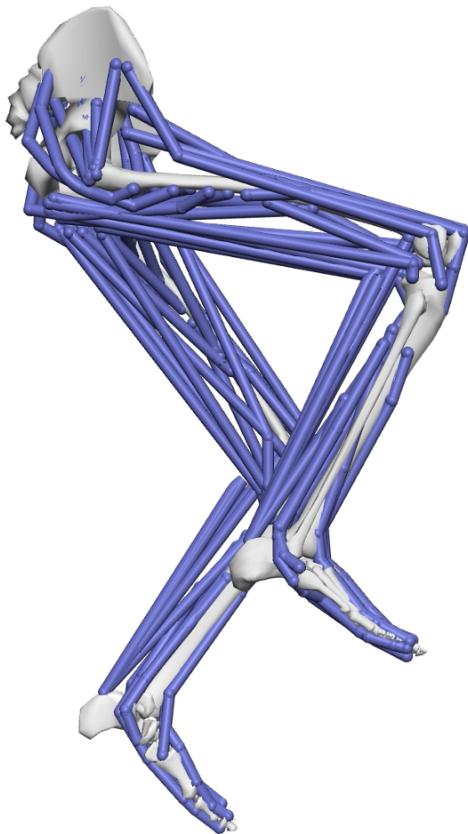


A



B

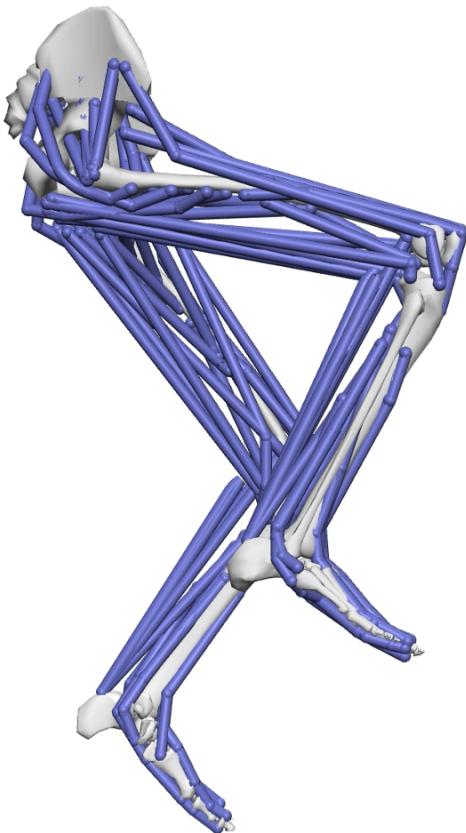
Musculoskeletal Model – Joint Reaction Force



Gravity
Ground Reaction Forces
Muscle Forces +

Total Forces @ Joint

Musculoskeletal Model – Joint Reaction Force



Gravity
Ground Reaction Forces
Muscle Forces +

Total Forces @ Joint

Total forces must be balanced by something.
In this case it is the “joint” structures, e.g.,
cartilage-to-cartilage, ligaments, meniscus, etc.

Joint Reaction Force Validation - Gait

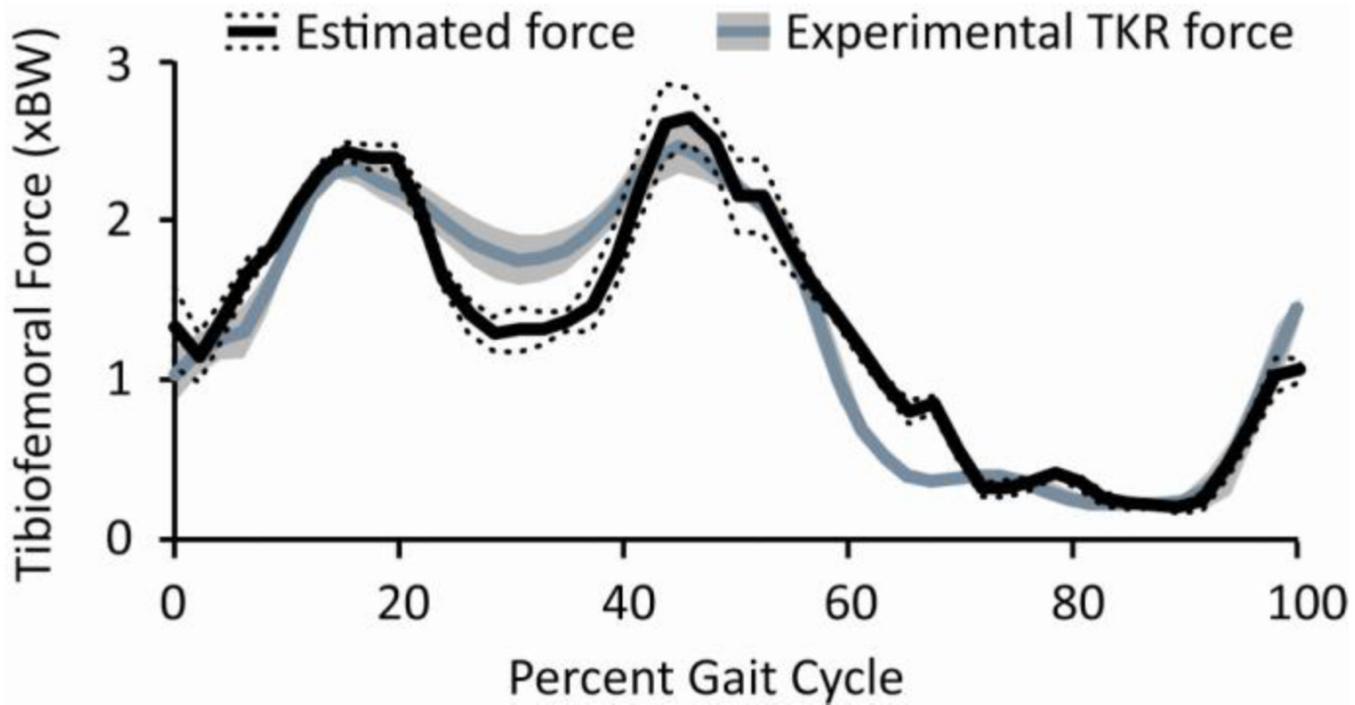
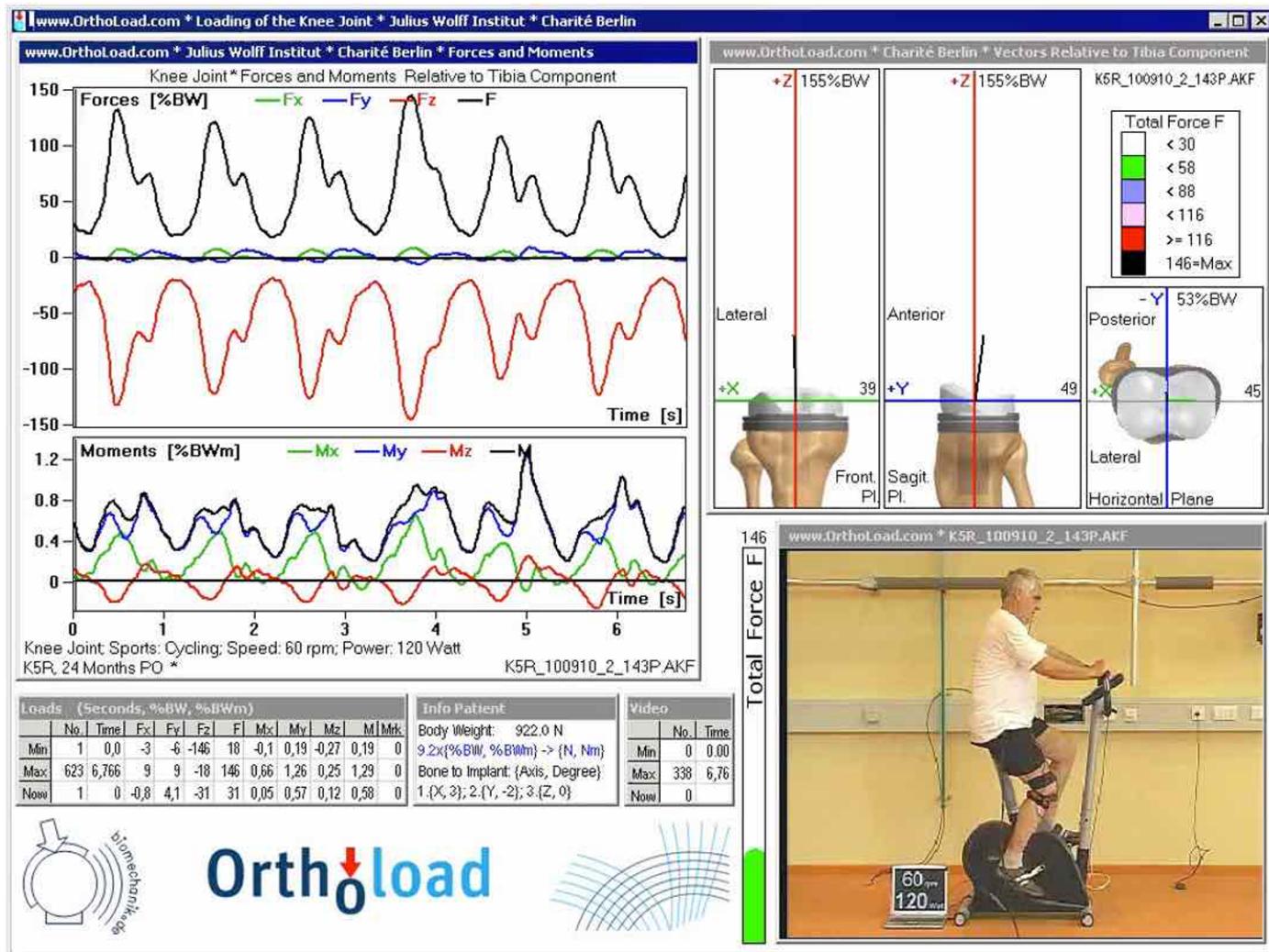
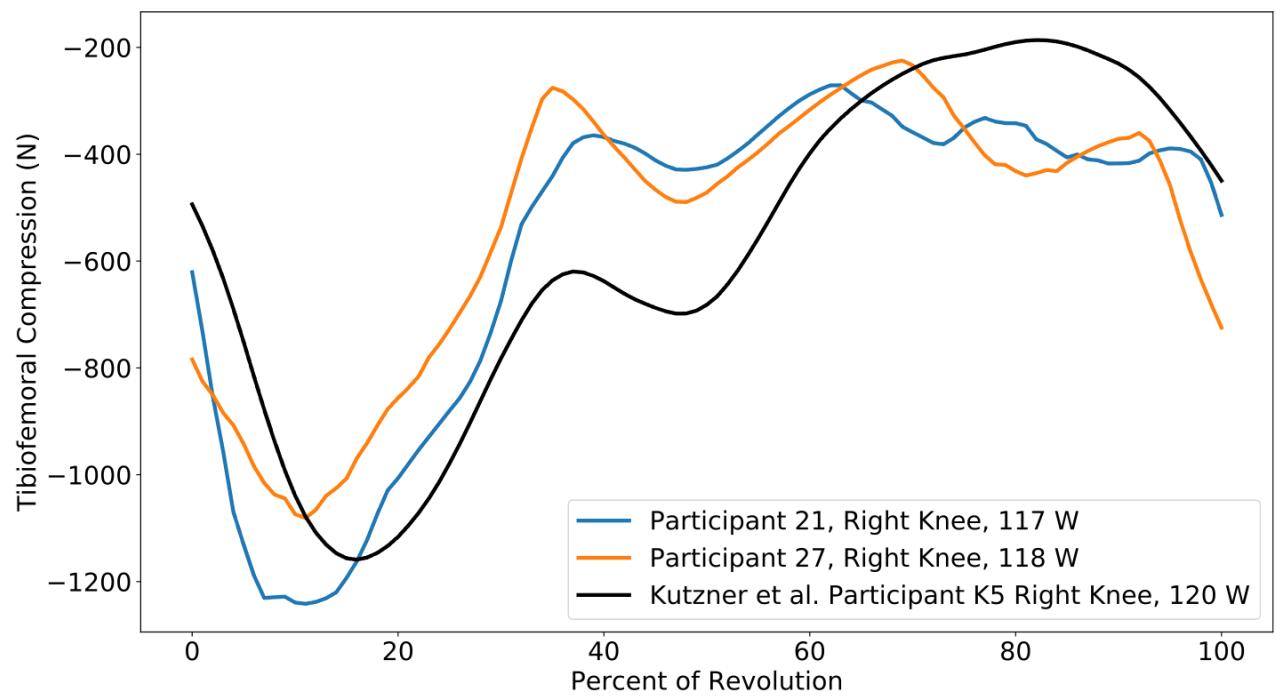
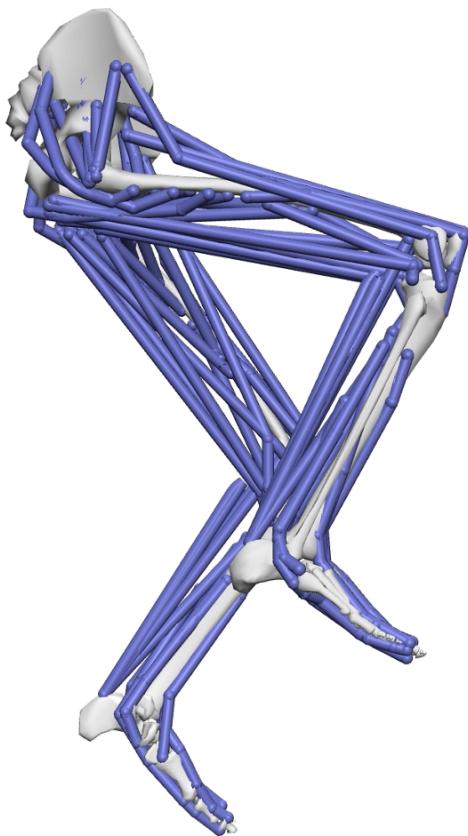


Fig. 1.
Tibiofemoral contact forces expressed in multiples of body weight (BW) from experimental forces measured using an instrumented total knee replacement (TKR, gray) and estimated with the computer model (black). The average ± 1 standard deviation is shown from four trials.

Joint Reaction Force Validation - Bicycling



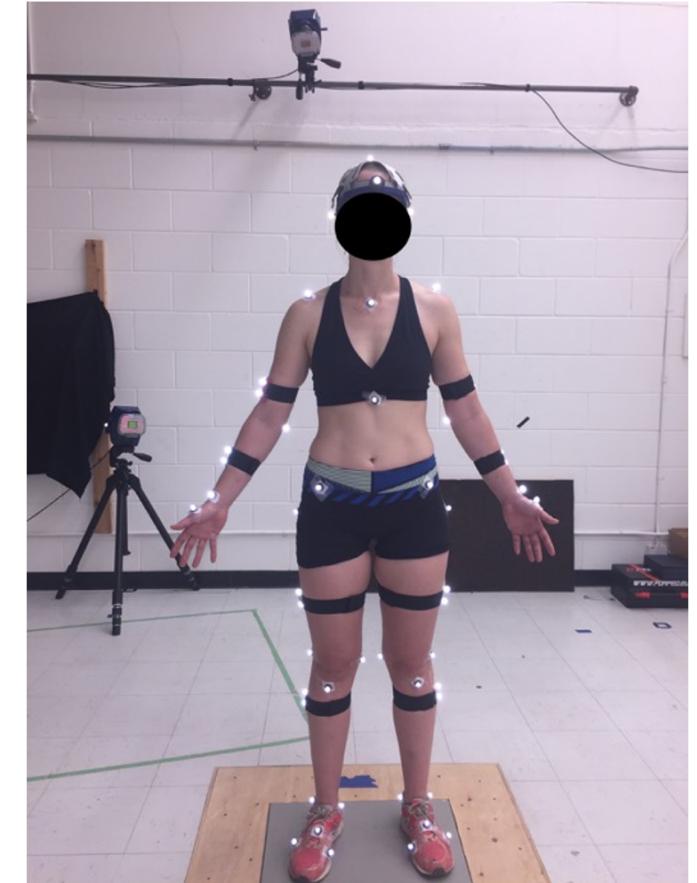
Joint Reaction Force Validation - Bicycling



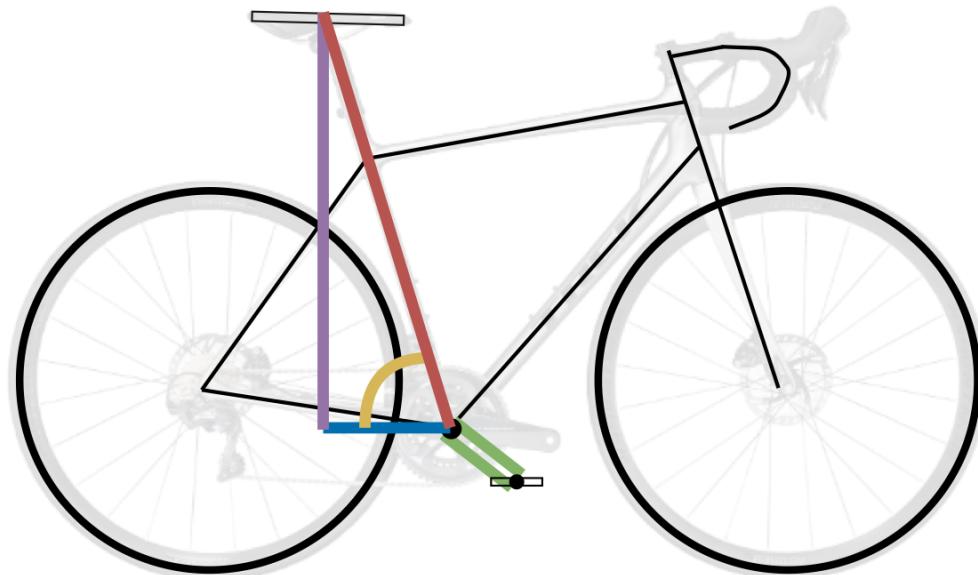
Effect of Bicycle-Fit on Knee Joint Reaction Forces

Methods

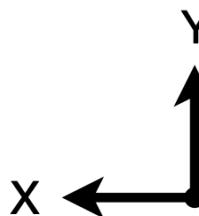
- 18 bicycling bouts (3-minutes each)
 - 70-75% max HR
- 40 markers lower body
- Processed data for last 1-minute



Bicycle Fit – Saddle X & Saddle Y



- = Seat Tube
- = Crank Arm
- = Seat Tube Angle
- = Saddle X
- = Saddle Y



Fit Bike Pro 1 (Purely Custom, USA)

Experimental positions

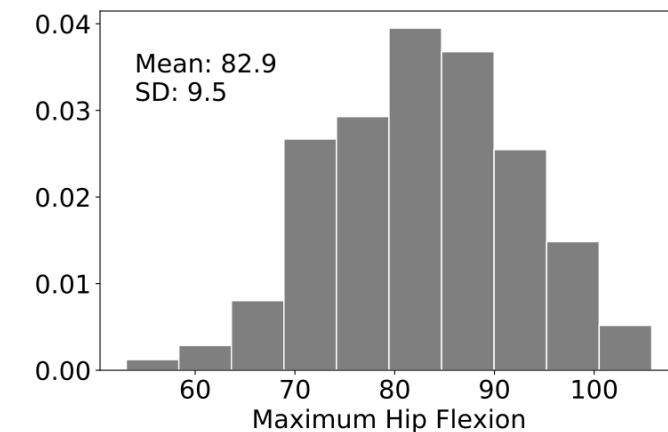
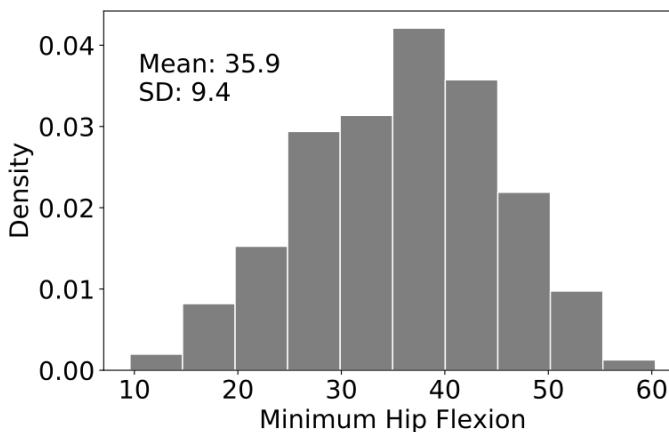
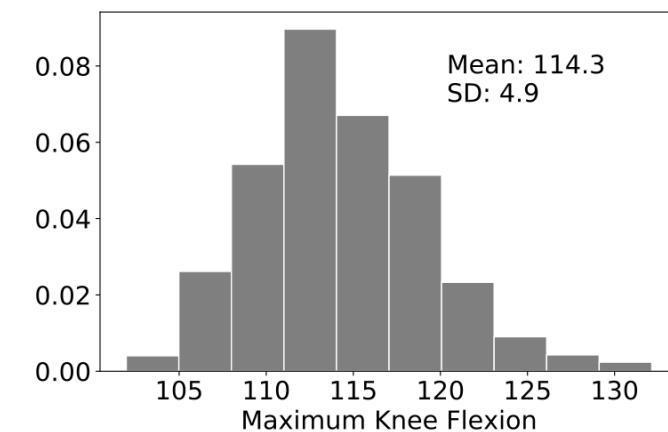
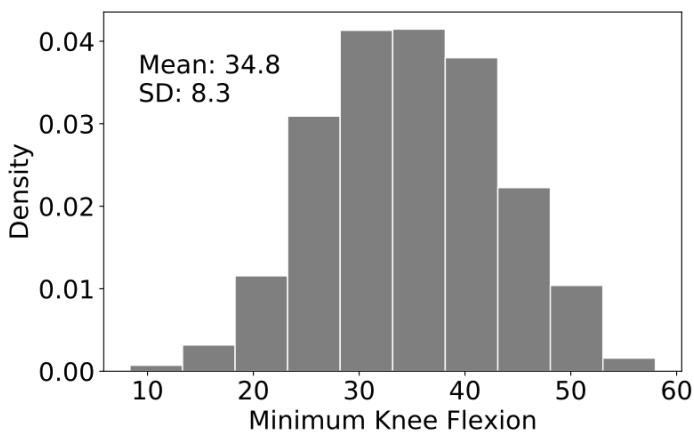
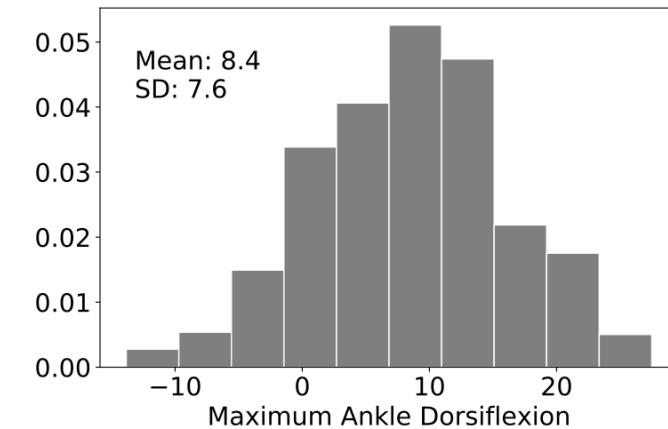
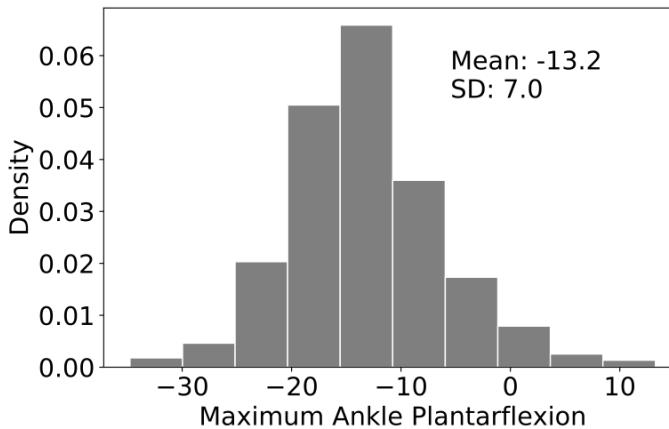
Saddle X	Saddle Y	Crank Arms
Commercial	Commercial	172.5 mm
+/- 10% commercial	+/- 5 % commercial	170 or 175 mm
+/- 10% commercial	+/- 5 % commercial	

Experimental positions

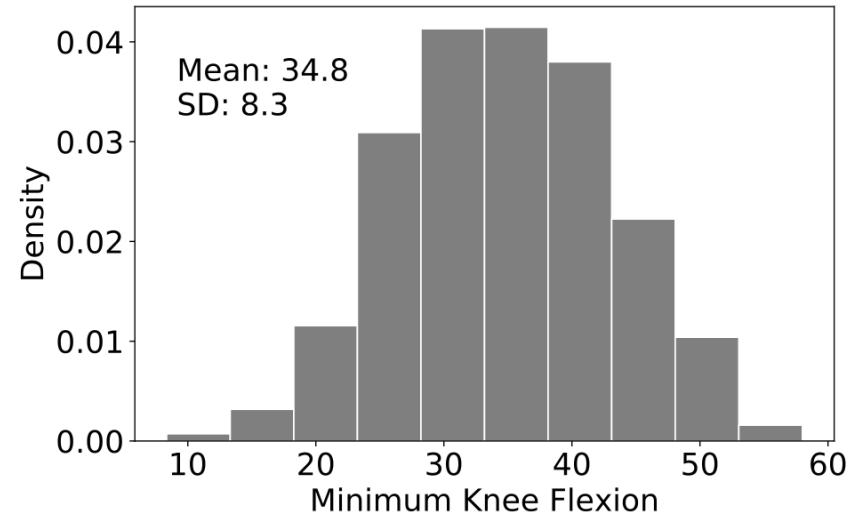
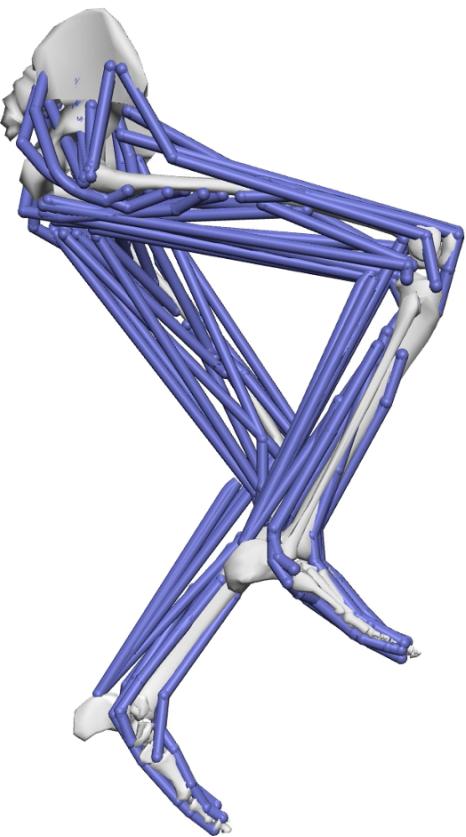
Saddle X	Saddle Y	Crank Arms
Commercial	Commercial	172.5 mm
+/- 10% commercial	+/- 5 % commercial	170 or 175 mm
+/- 10% commercial	+/- 5 % commercial	

$3 \times 3 \times 2 = 18$ *positions*

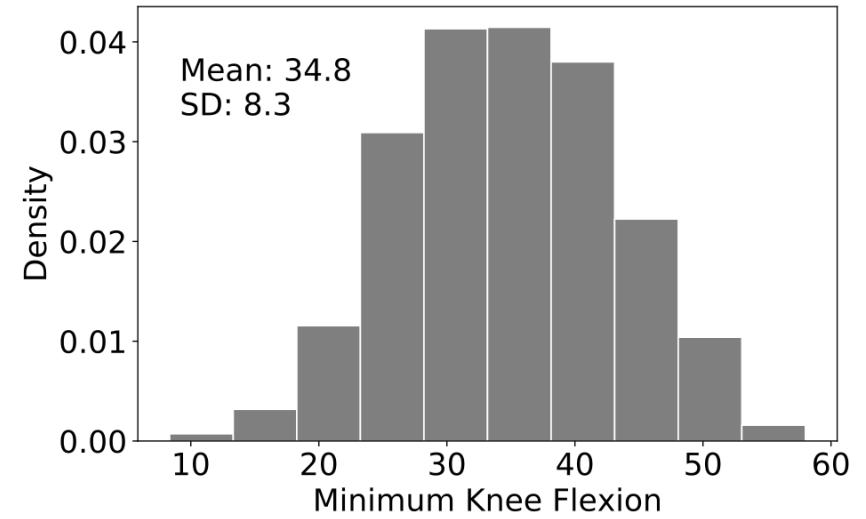
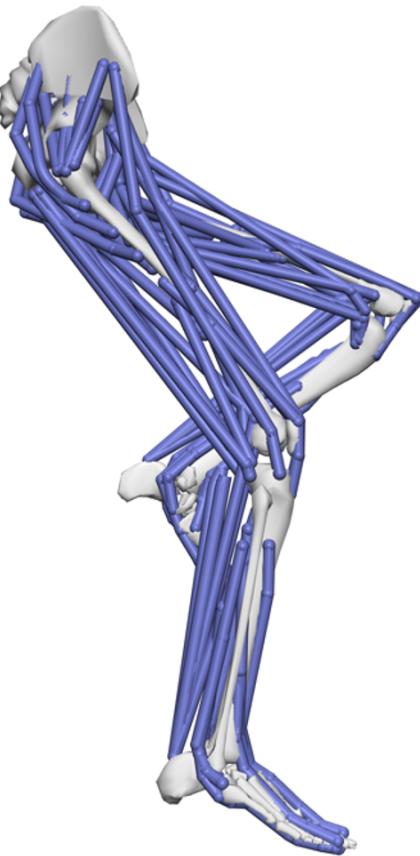
Experimental Positions



Experimental Positions

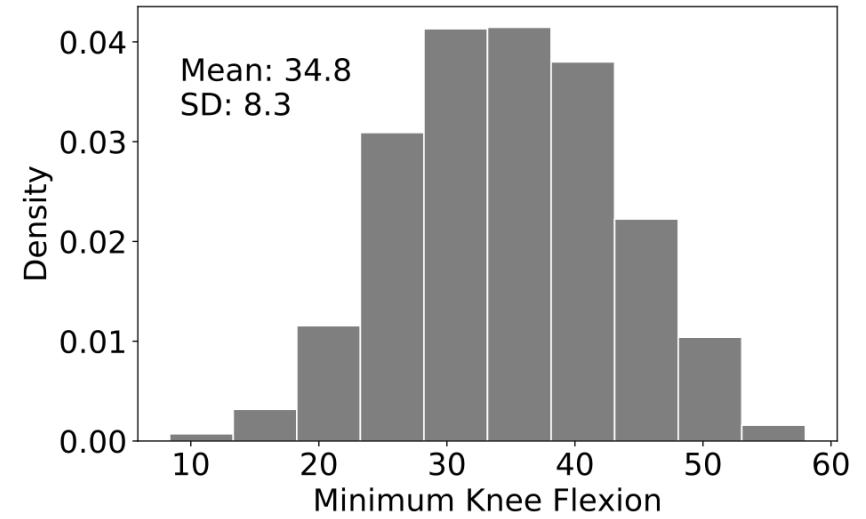
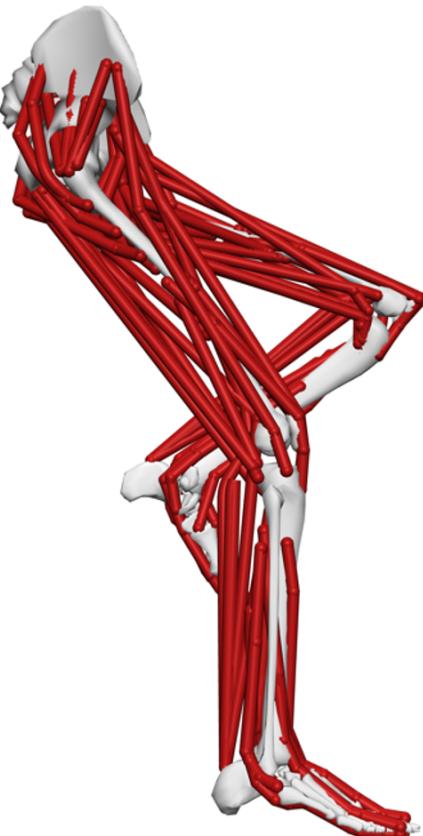


Experimental Positions



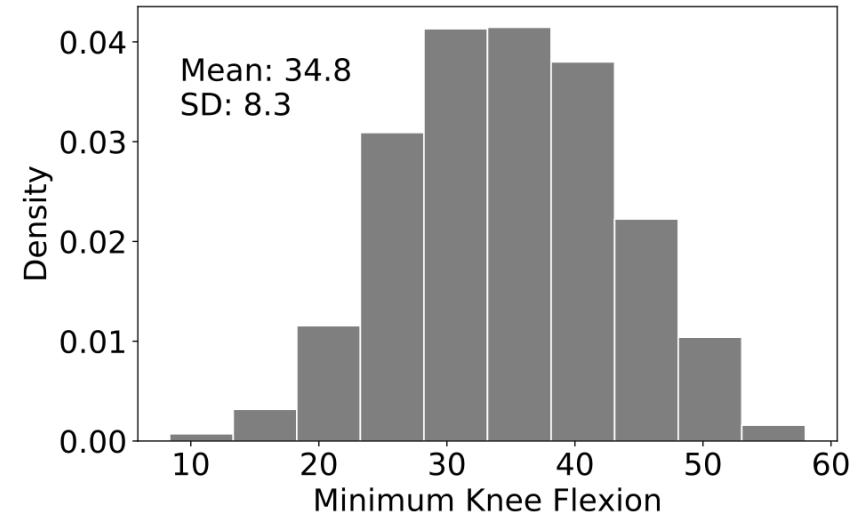
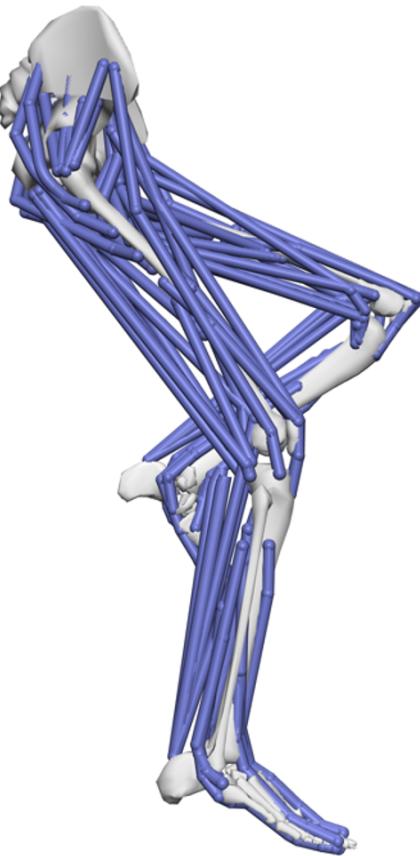
43°

Experimental Positions



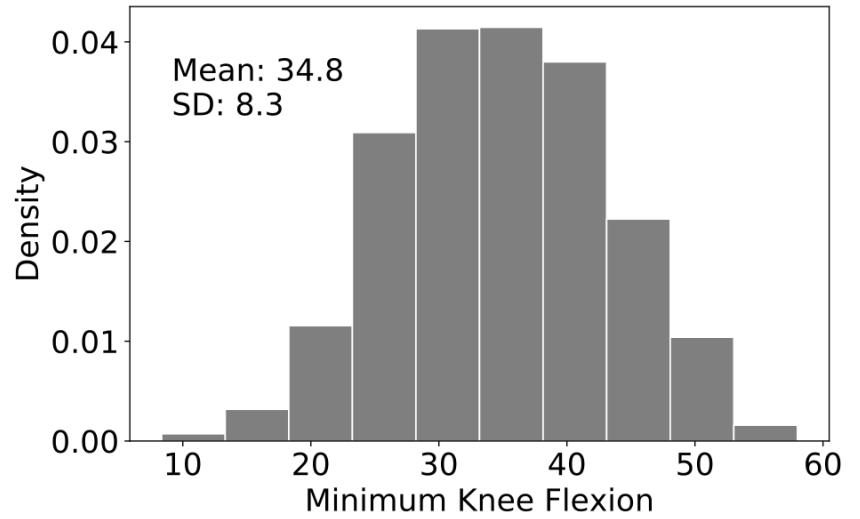
35°

Experimental Positions



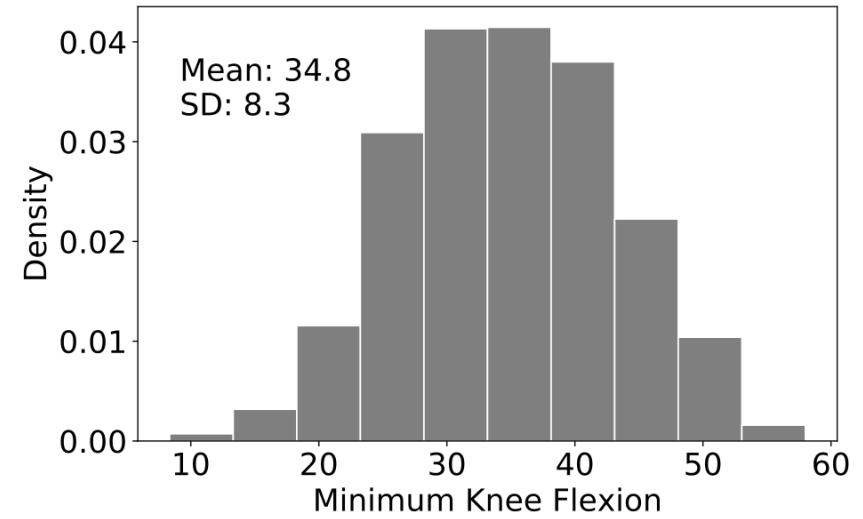
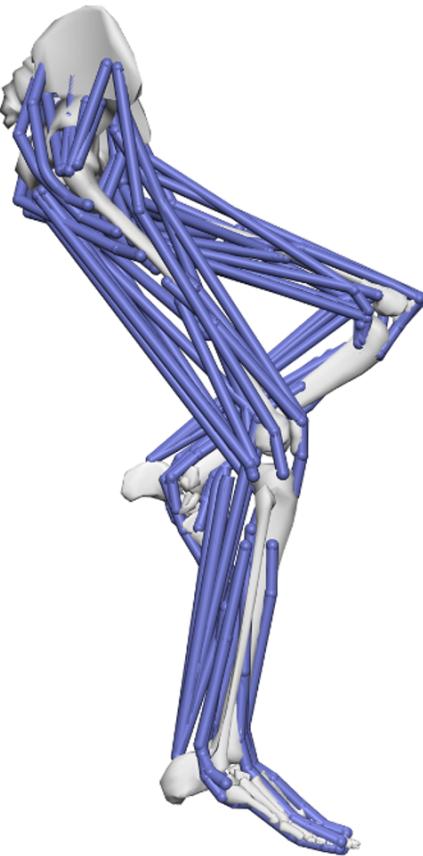
43°

Experimental Positions



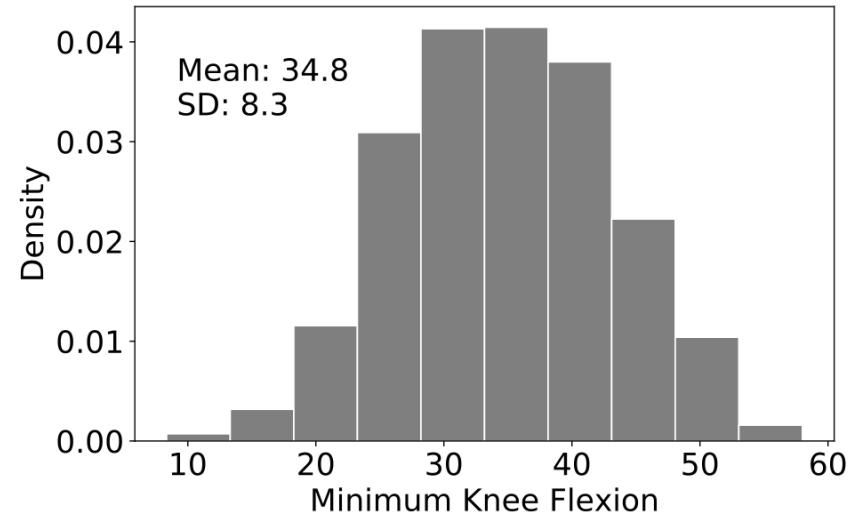
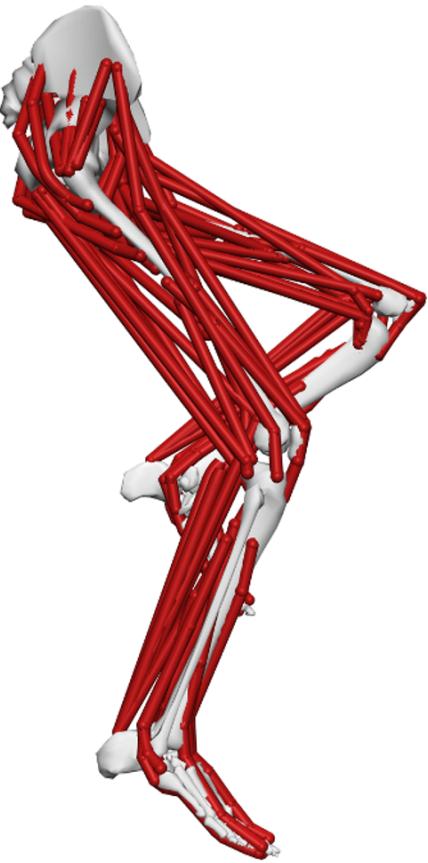
10°

Experimental Positions



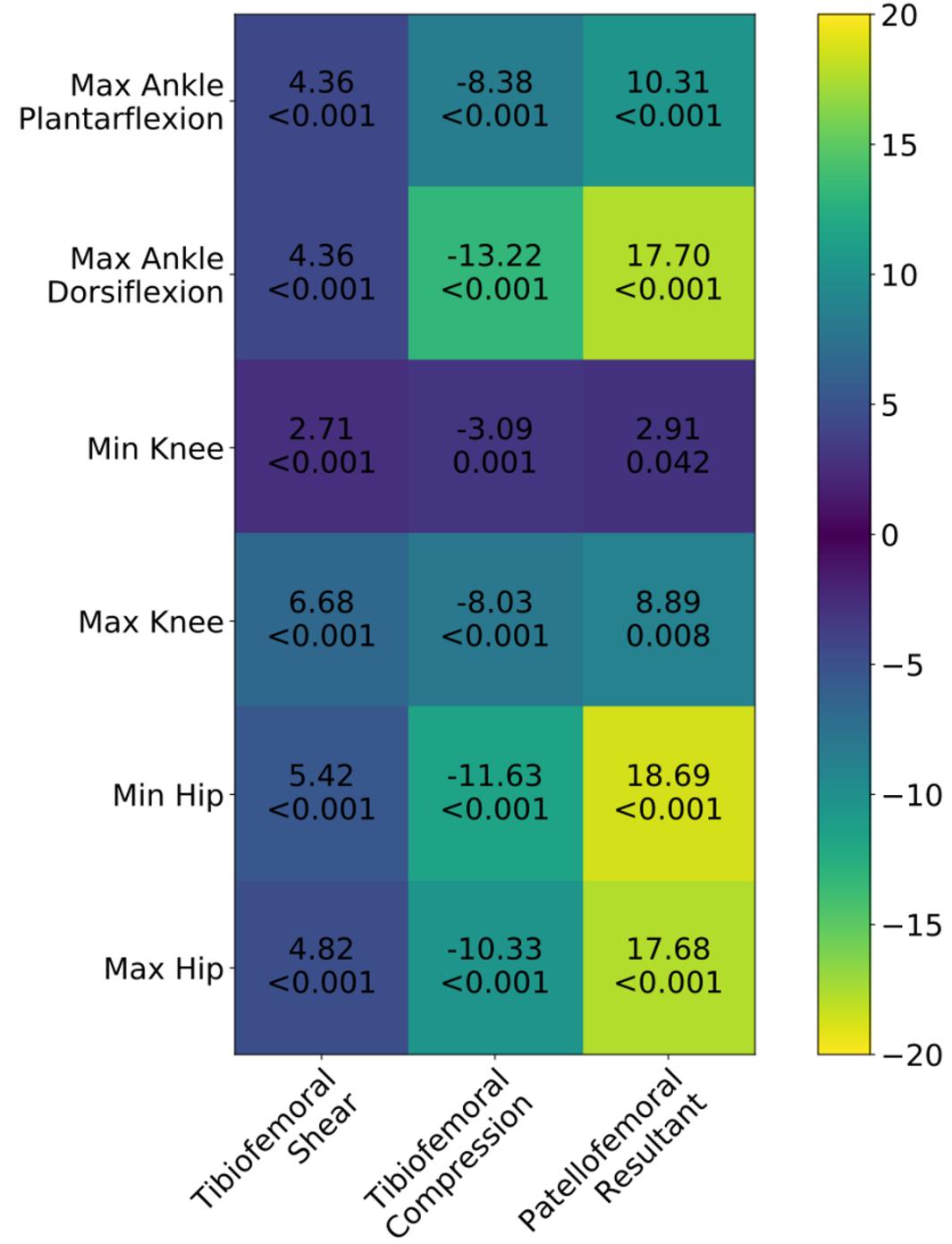
43°

Experimental Positions



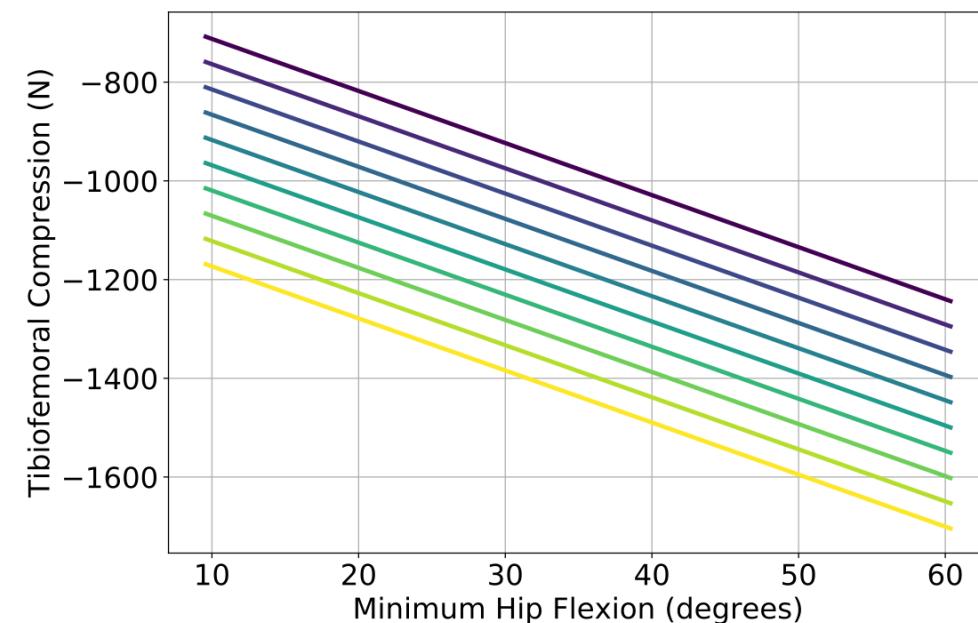
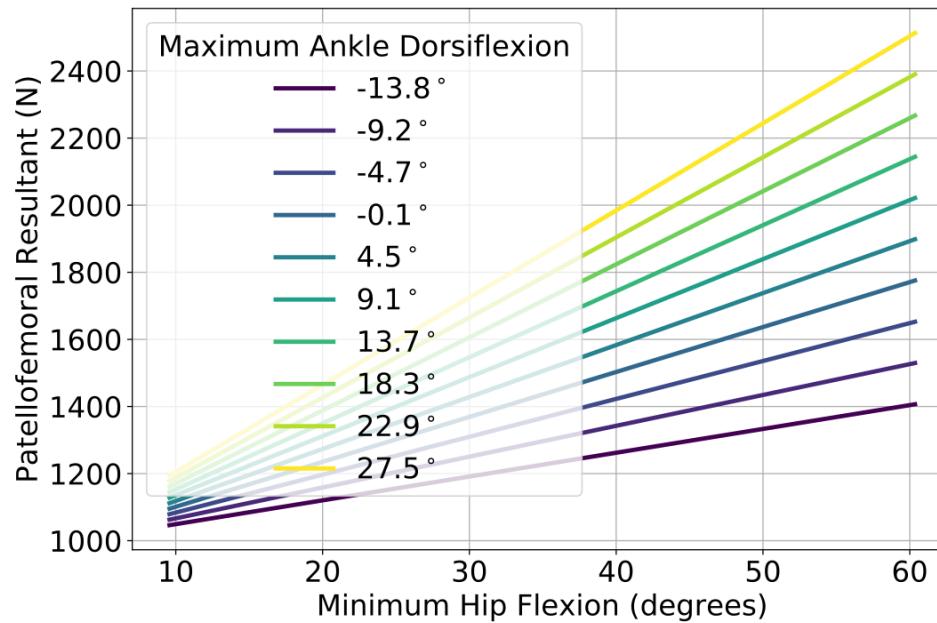
55°

Joint Kinematics v. Joint Reaction Forces



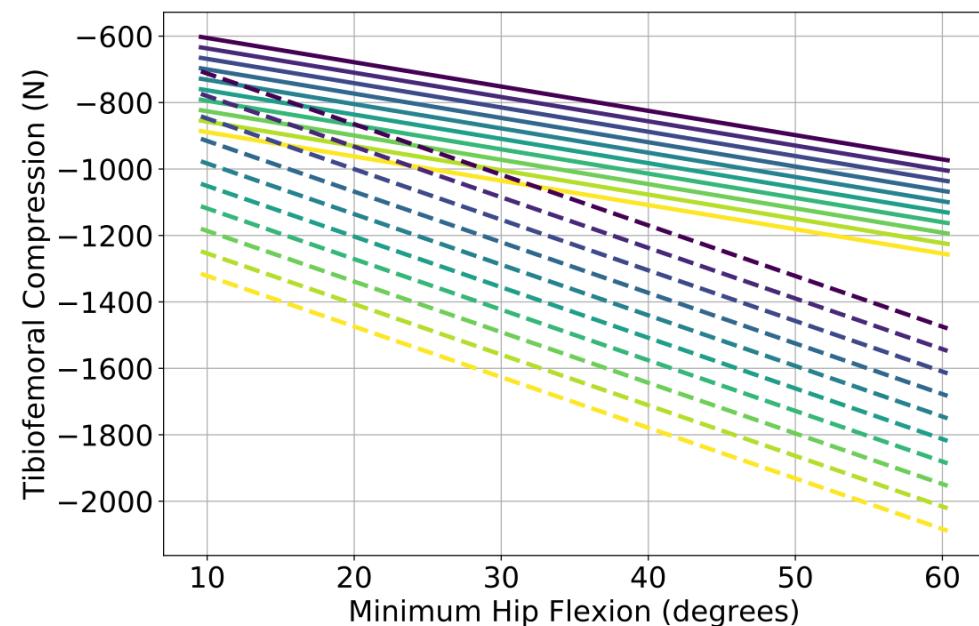
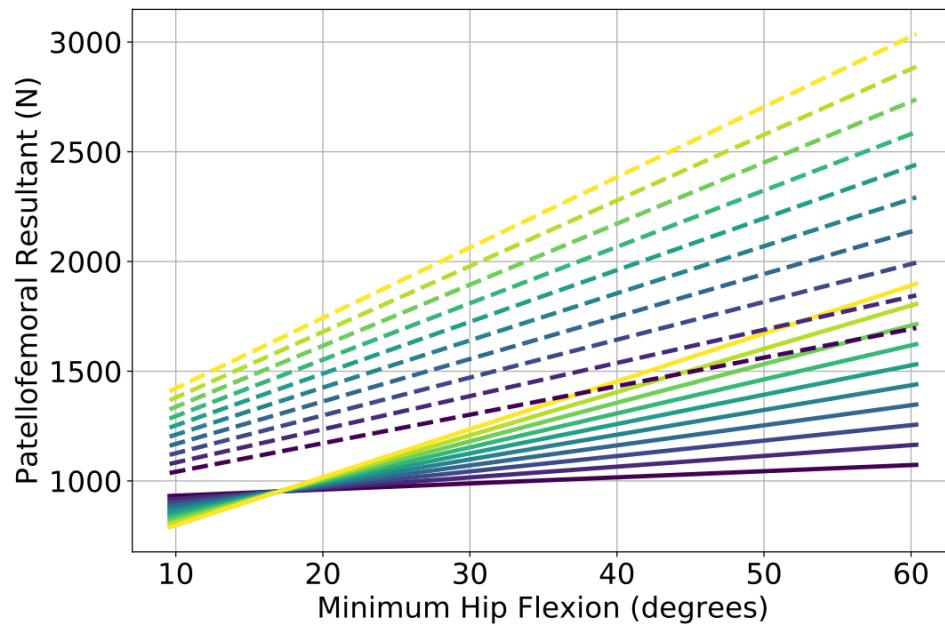
Joint Kinematics v. Joint Reaction Forces

Interactions



Joint Kinematics v. Joint Reaction Forces

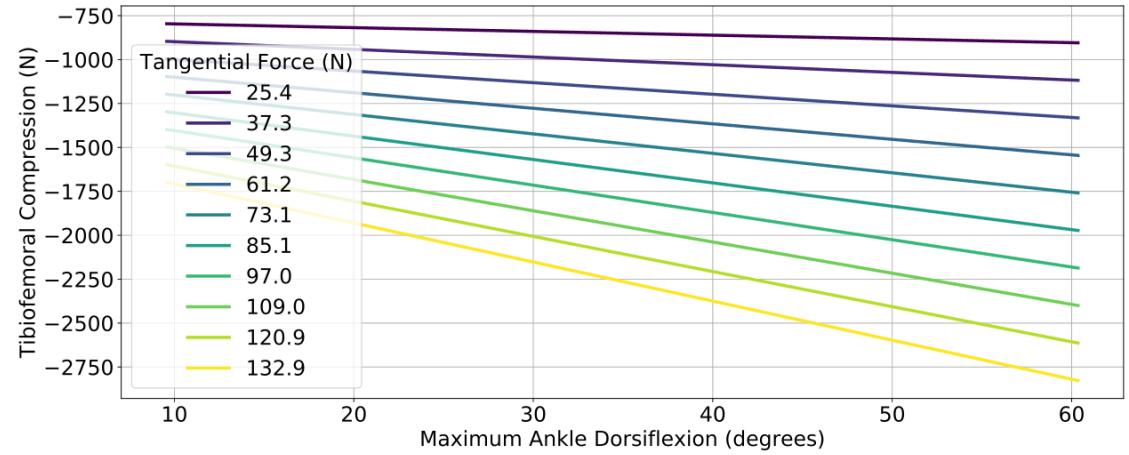
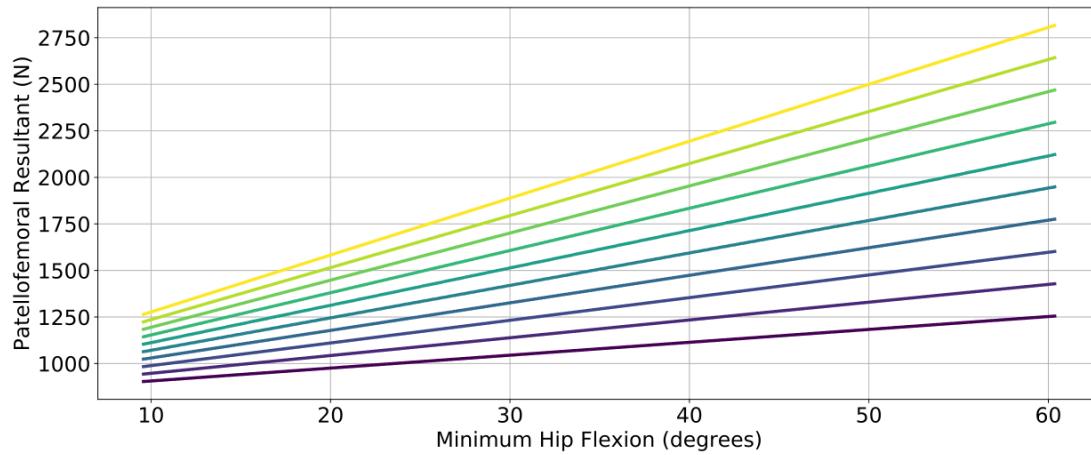
Sex Differences



N.B. Uses same legend as previous slide

Joint Kinematics v. Joint Reaction Forces

Intensity Differences



Joint Kinematics v. Joint Reaction Forces

Take Home

Higher Flexion (all joints)
Multiplicative
Higher Intensity



Effect of Bicycle & Walking on Osteoarthritic Cartilage

Study Design - Ongoing

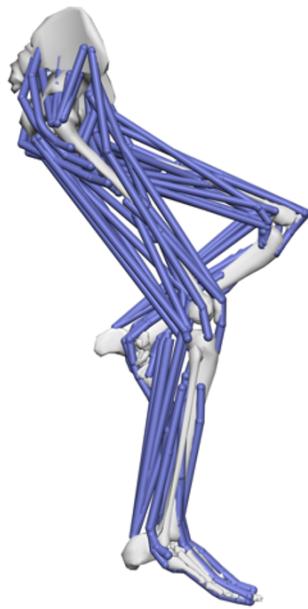
- Similar to running vs. bicycling MRI study
- Same duration walking & cycling (25 minutes)
- Estimate cumulative load of each (impulse * steps/revolutions)
- Estimate energy expenditure of each (HR based calorie expenditure)
- Determine which activity has greatest impact on cartilage deformation & how this compares to energy expenditure, cumulative knee loads, and peak knee loads.

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Questions?

