Smaller Ankle Muscle Forces During Rising Reduce Ankle Joint Contact Forces After Injury

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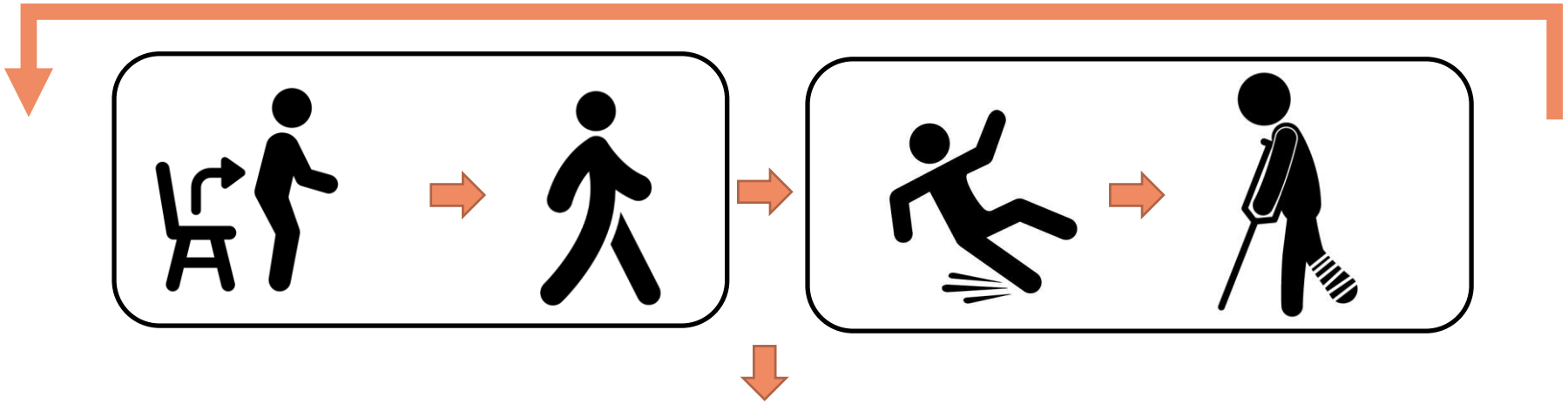
Problem

Transitional Movements [1,2]



Optimize Movement for Stability and Pain Reduction [3]

How can we quantify biomechanical compensation mechanisms after an injury?

[1] E. van der Kruk, et al., 2021. [2] Alexander, et al., 2001. [3] Moisan, et al., 2021.

Related Work

Chronic Ankle Instability: Ankle instability caused by repeated ankle sprains [4]

Muscle Activity

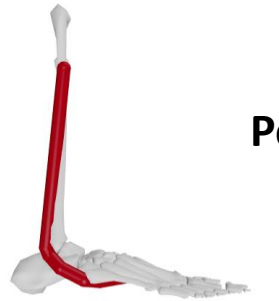
Individuals with chronic ankle instability had reduced
- plantarflexor muscle activity [4,5]
- ankle joint moments [6]

Compared to healthy control participants

Joint Loading

Greater peroneus longus activity hypothesized to modulate ankle loading at heel strike while walking [7]

Soleus



Peroneus Longus

[4] Moisan, et al., 2017. [5] Feger, et al., 2015. [6] Hertel, et al., 2019, [7]. SJ Son, et al., 2019.

Research Objective

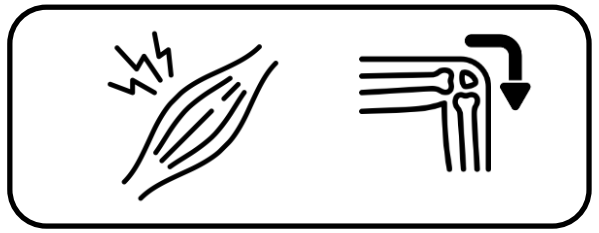
Transition Movements

Prioritize Biomechanical Stability

Injuries Introduce Compensation

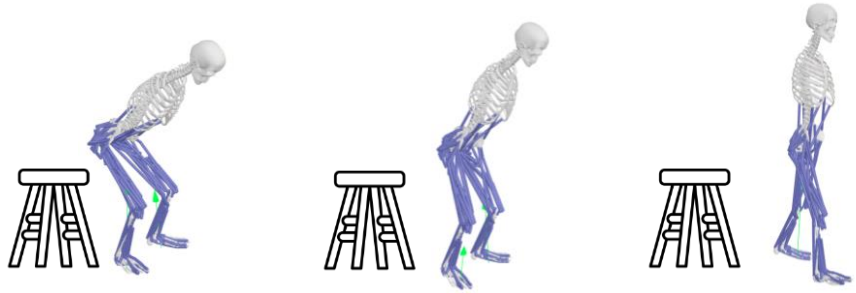
Reevaluate Movement Strategy

Altered Muscle Recruitment & Kinematics



Quantify Compensation Mechanisms

Dynamic muscle forces and joint contact loads **can't** be measured non-invasively



Develop movement simulations of musculoskeletal models to **quantify how ankle injury affects movement biomechanics** when rising and walking tasks are merged

Experimental Data Collection

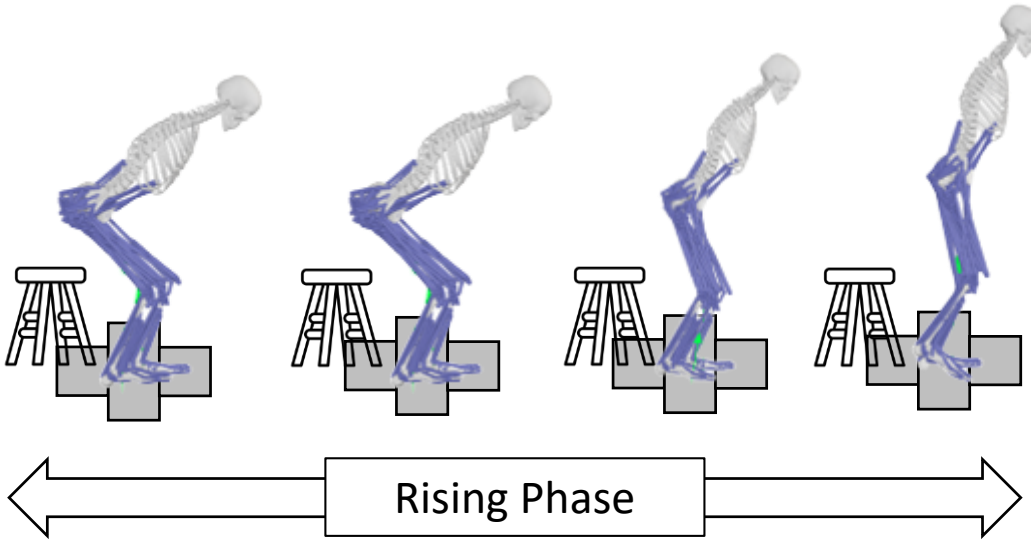
Two young adult participants

Healthy: F, 24 yrs, 1.61 m, 80.74 kg

Injured: F, 24 yrs, 1.66 m, 55.71 kg

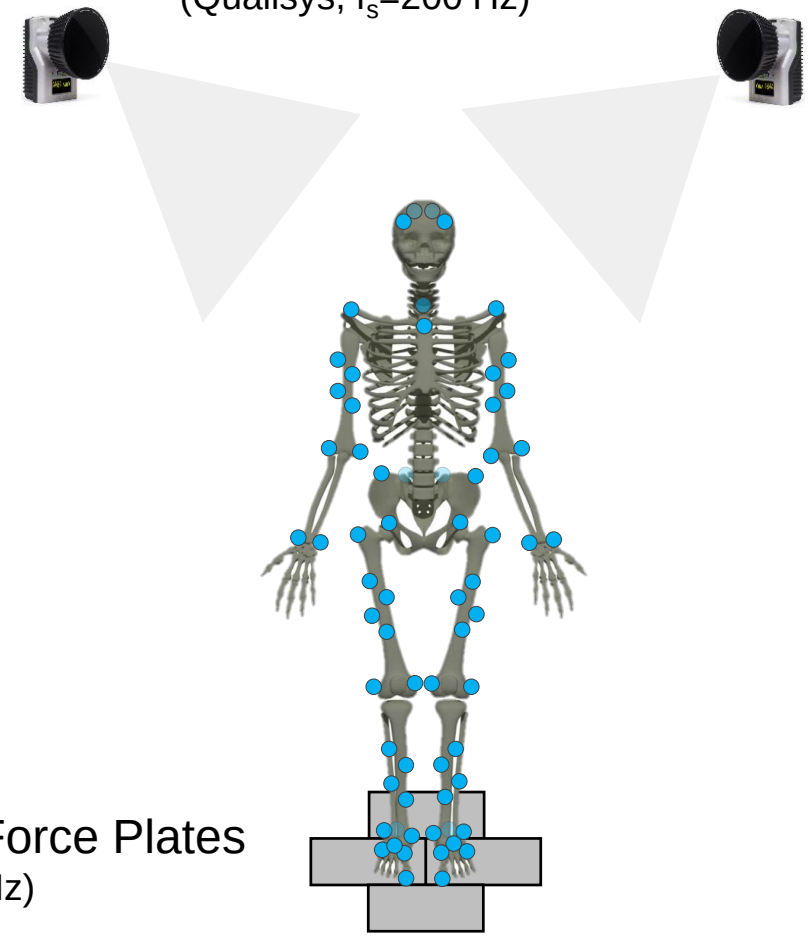
- Closed fracture on right tibia and talus
- Participated after 4 months weight bearing

Sit-to-Walk Protocol [8]



[8] Blaszcyk, et al., 2000.

Optical Motion Capture
(Qualisys, f_s=200 Hz)



4 In-ground Force Plates
(AMTI, f_s=2000 Hz)

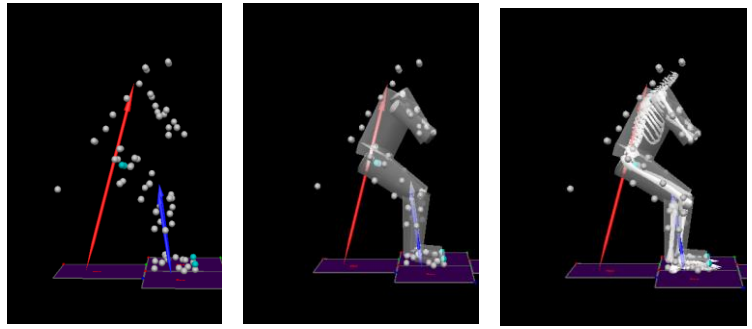
Full-body Marker Set

Simulation Workflow

Experimental sources

3D Motion Capture
Ground Reaction Forces

Visual3D link model



Simulation inputs

Inverse kinematics (IK)
Lowpass 6 Hz

GRFs and centers of pressure
Lowpass6 Hz

Segment size scale factors

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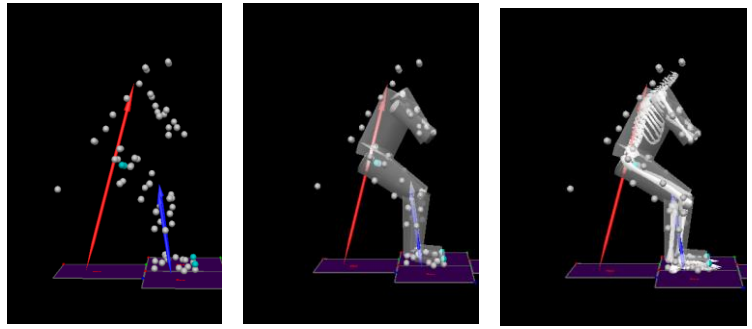

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Gait2392:
Lower Limb Model

92 Hill-type musculotendon actuators

23 Degrees of freedom

OpenSim 4.4 [9]

[9] Delp, et al., 2007 (simtk.org).

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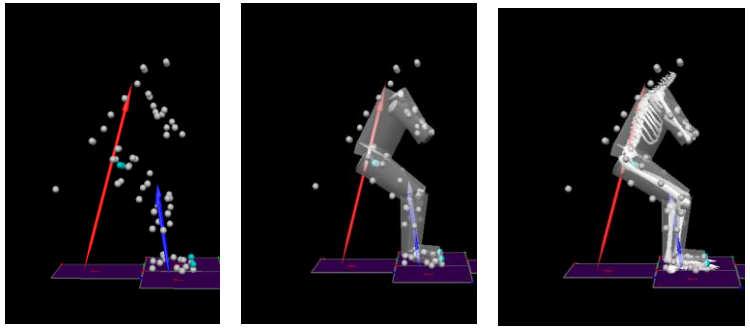

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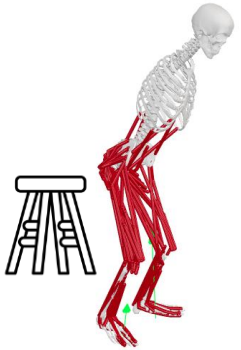
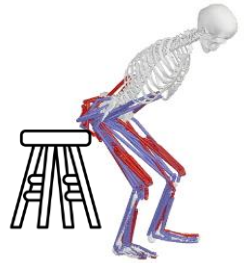
OpenSim 4.4 [9]

Residual Reduction Algorithm [10]



Adjusted model
Dynamically consistent IK

Computed Muscle Control [11]



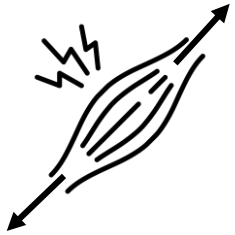
Muscle activations and **forces** [12]

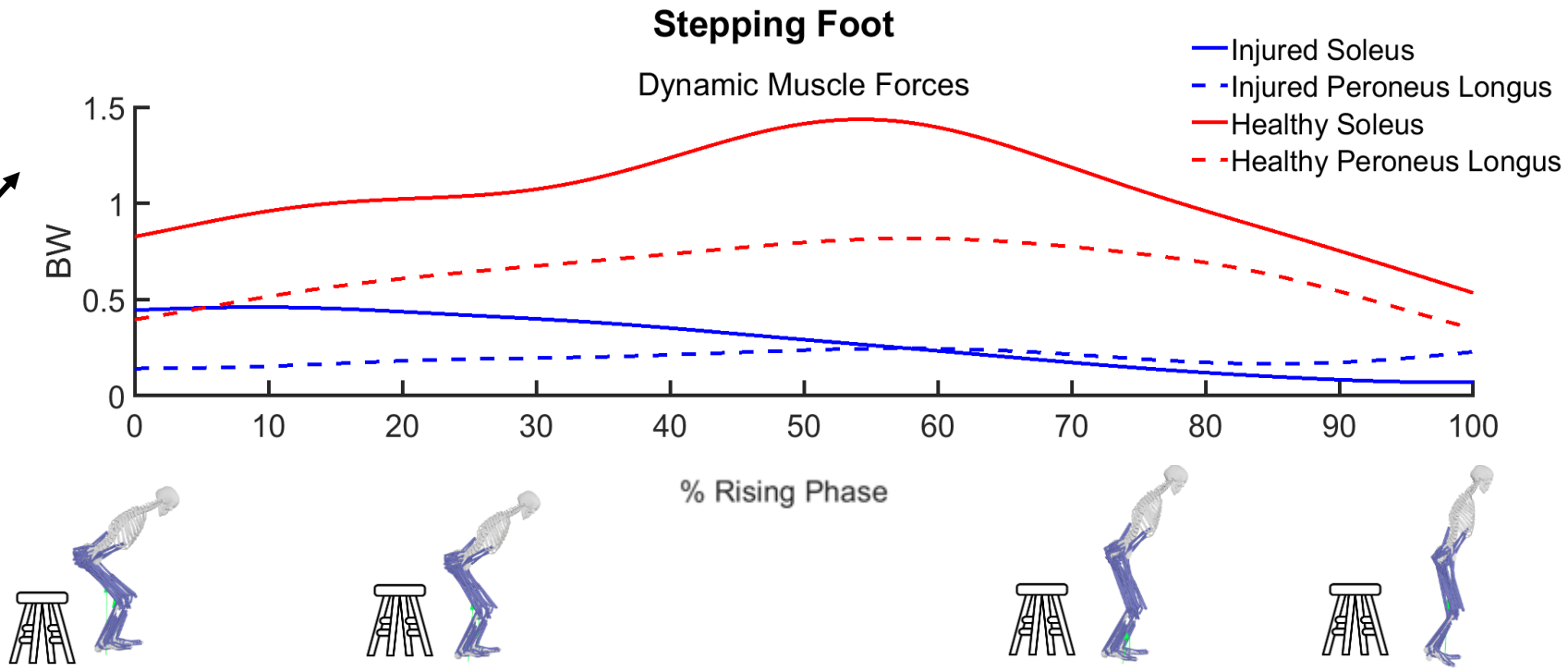
Analysis:

- Resultant ankle joint contact forces
- Peak muscle forces
  - Soleus, Peroneus Longus

[9] Delp, et al., 2007 (simtk.org). [10] Seth, et al., 2018. [11] Thelen and Anderson, 2006. [12] Hicks, et al., 2015.

Muscle and Joint Contact Forces





3.5x greater peroneus longus force for heathy participant

Healthy participant's soleus produced 87% greater force than injured participant

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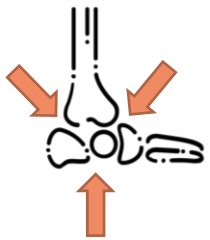
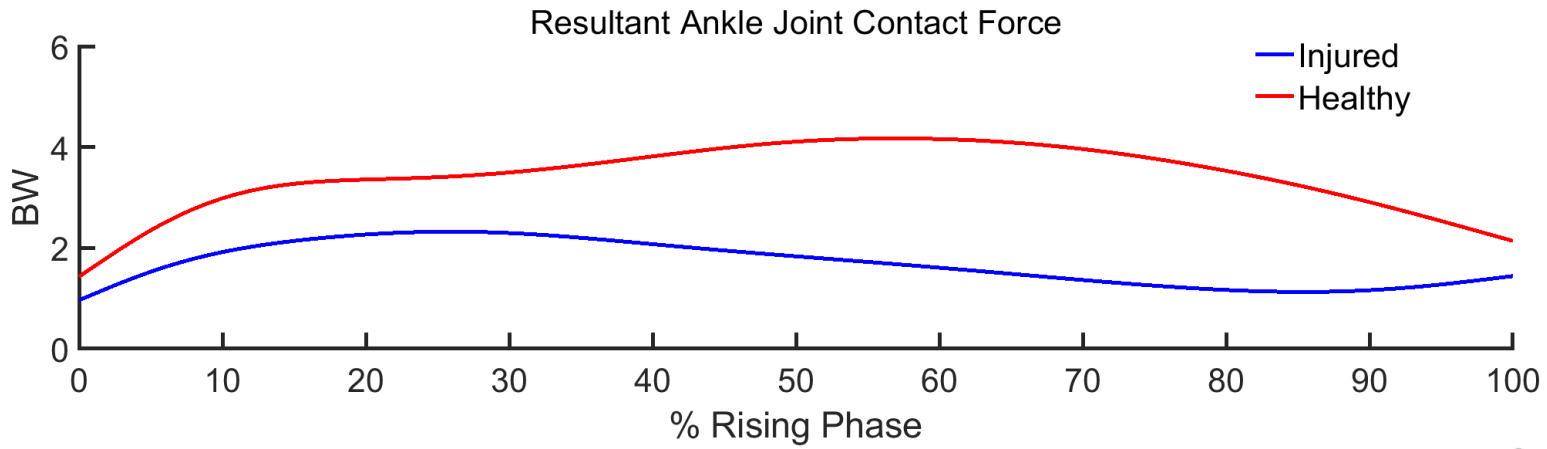
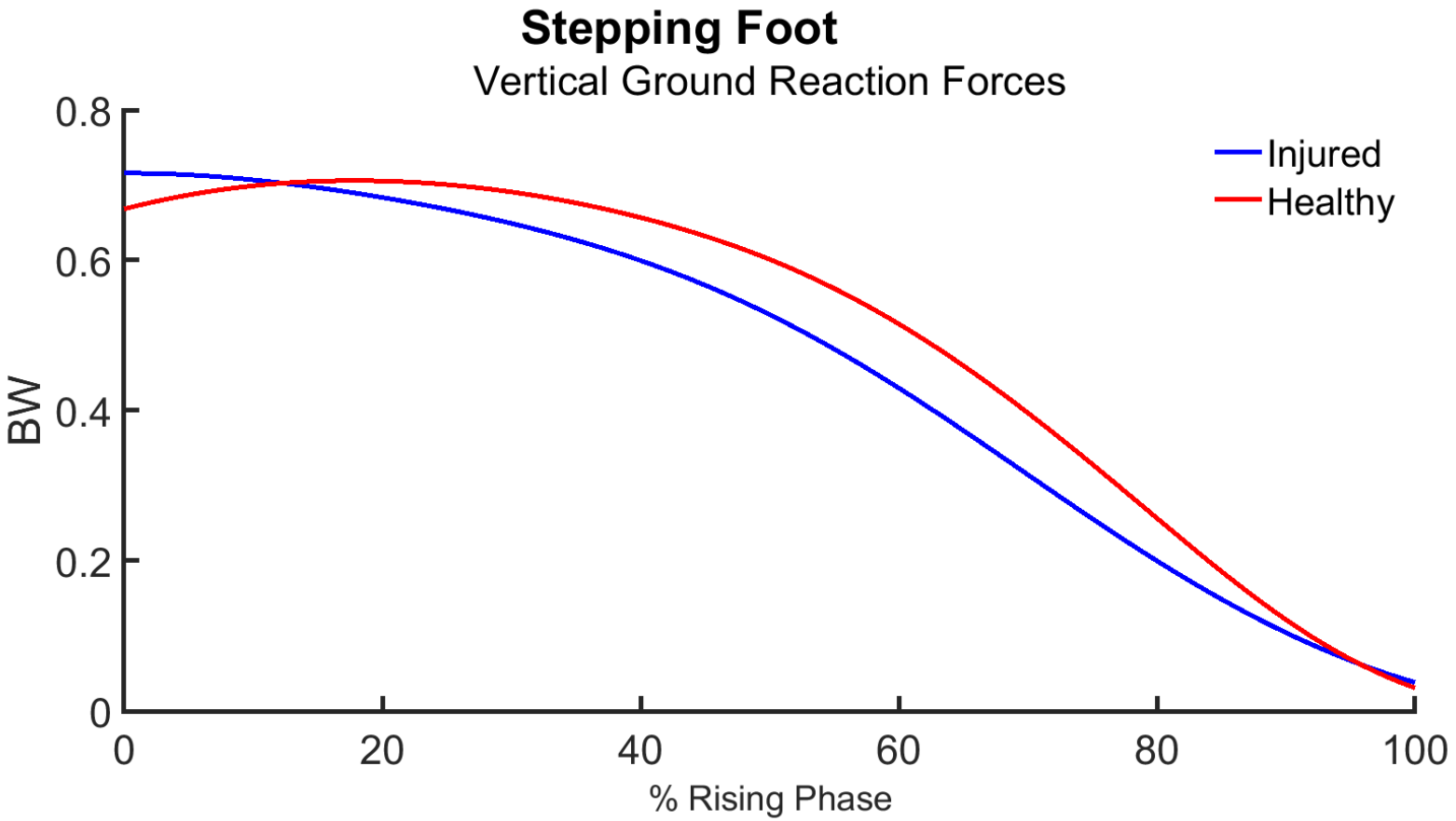




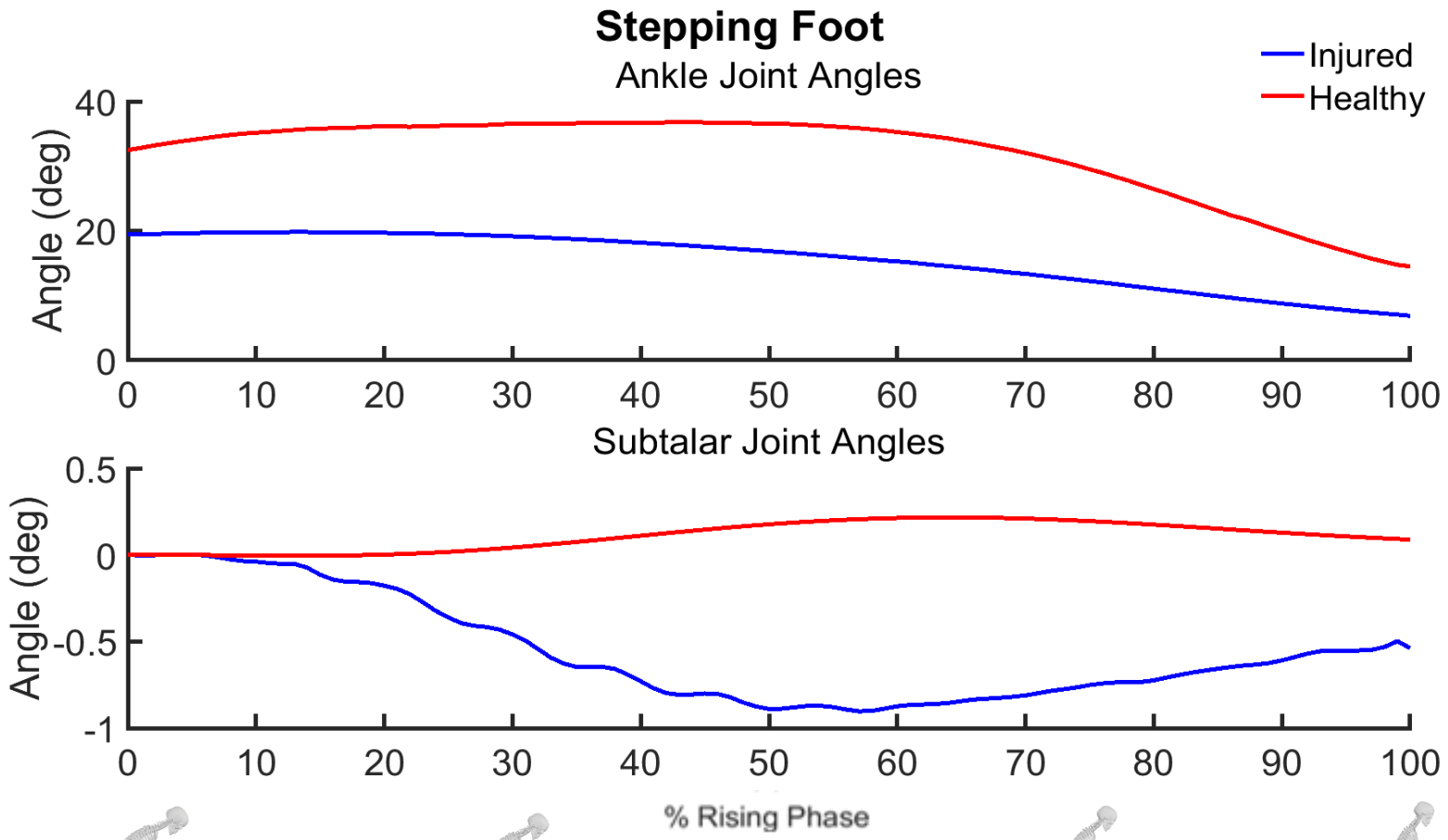
2.3x greater resultant ankle joint contact force for healthy ankle

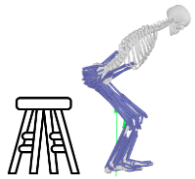
Ground Reaction Forces

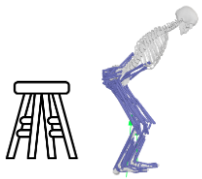


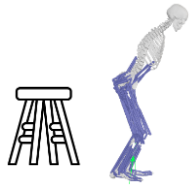
- Vertical GRFs indicate slightly less vertical load sharing for injured foot
- Kinetics alone don't support offloading of ankle joint

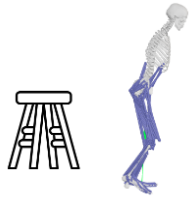
Joint Angles







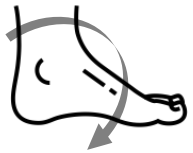


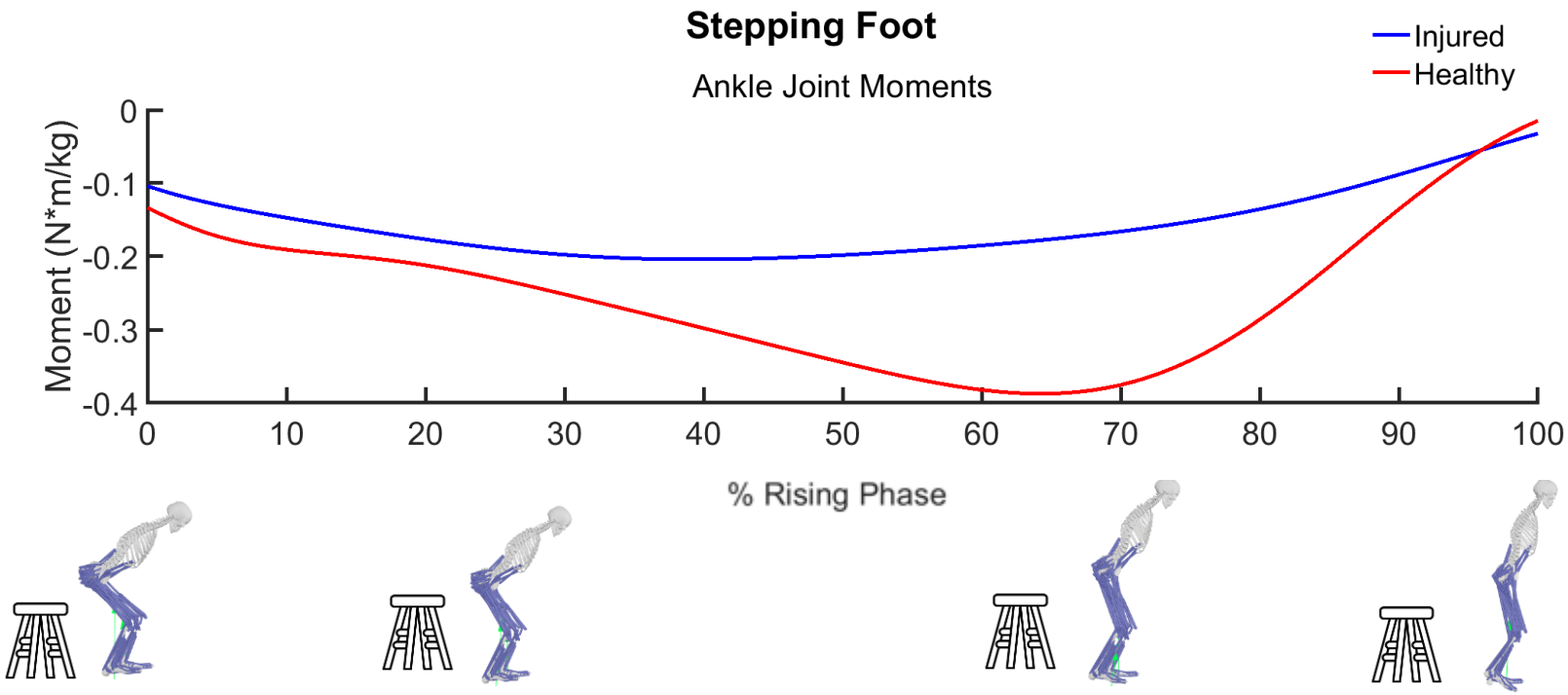


- Injured ankle had reduction in range of motion during rising plantarflexion

- Altered subtalar joint angle leads to small inversion angle
  - Altered moment arm

Joint Moments

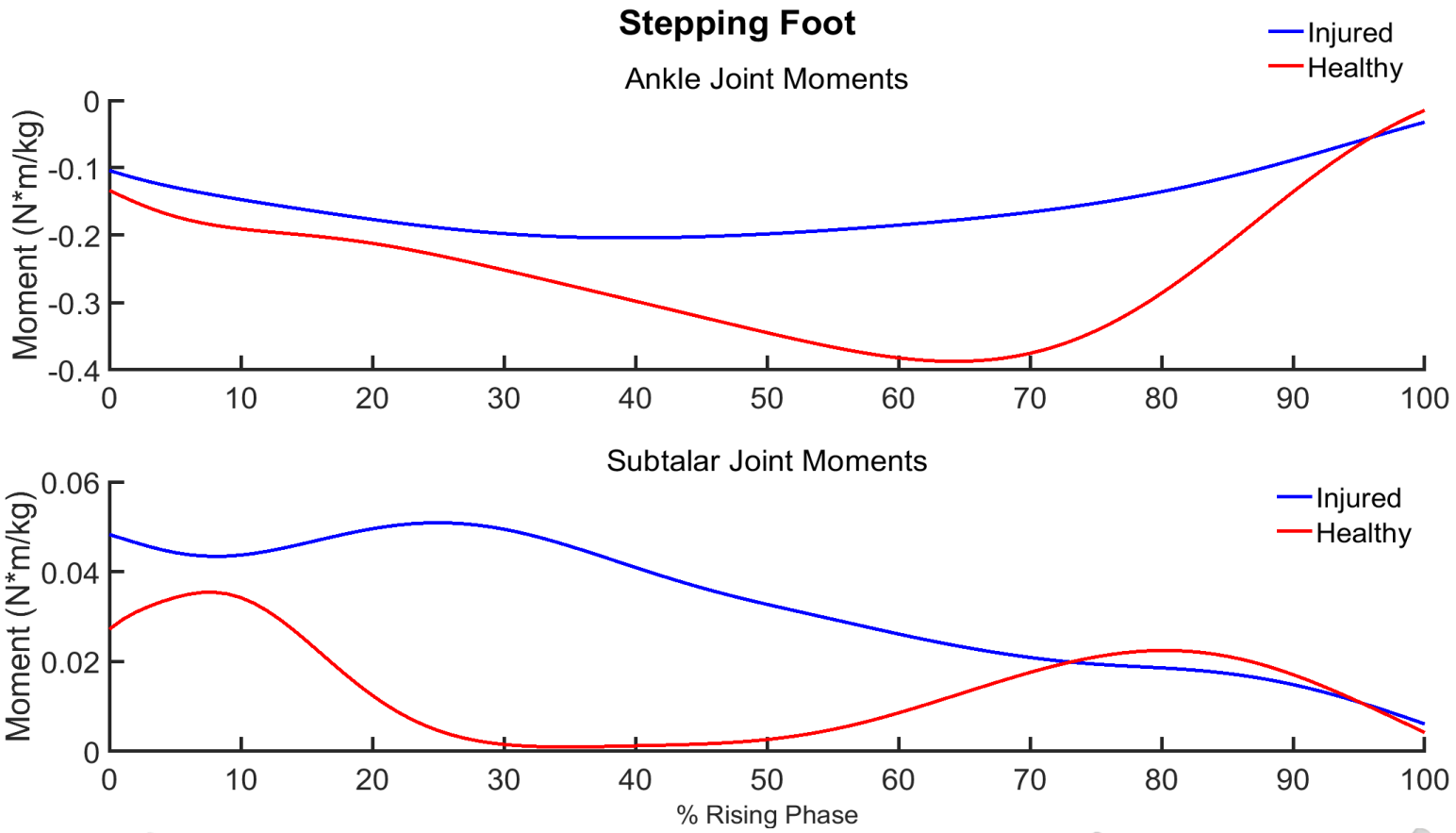


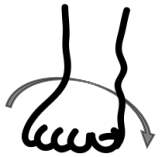


Reduced injured ankle joint moment [6]

[6] Hertel, et al., 2019.

Joint Moments

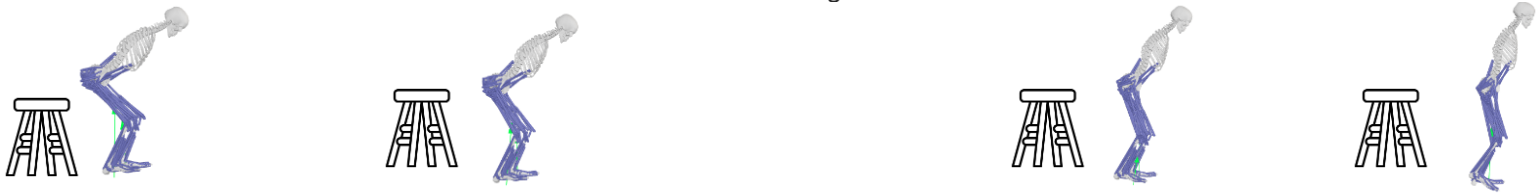




Reduced injured ankle joint moment [6]

Sustained inversion moment for injured and healthy ankle

Less muscle force required to complete the same task [4]



[4] Moisan, et al., 2017. [6] Hertel, et al., 2019.

Conclusions

Significance

- **Smaller in ankle muscle forces reduced ankle moment and resultant ankle joint contact force**
  - Protect joint and mitigate pain
  - Reduce muscle demand
  - Altered rising strategy post-injury
- **Smaller muscle forces could result from muscle atrophy and/or altered muscle control to offload the joint.**

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Clinical Relevance

- Rehabilitation and strength of soleus and peroneus longus is important for rising
- After 4 months weight bearing, we still observe altered biomechanics

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Future work

- Study additional muscles
- Analyze outcome metrics beyond rising phase
- More accurately model ankle injury (i.e., muscle atrophy)

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Questions?

Thank You!

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