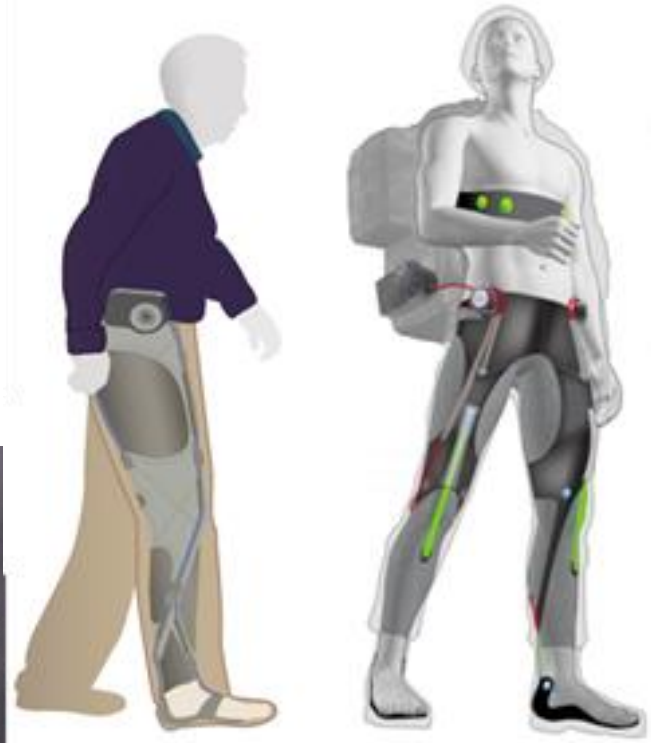
UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

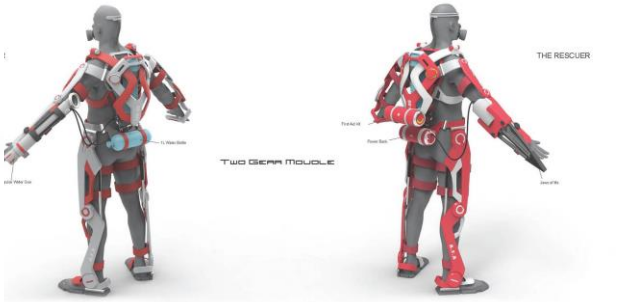
Mechanical Phantoms to Evaluate Exoskeletons

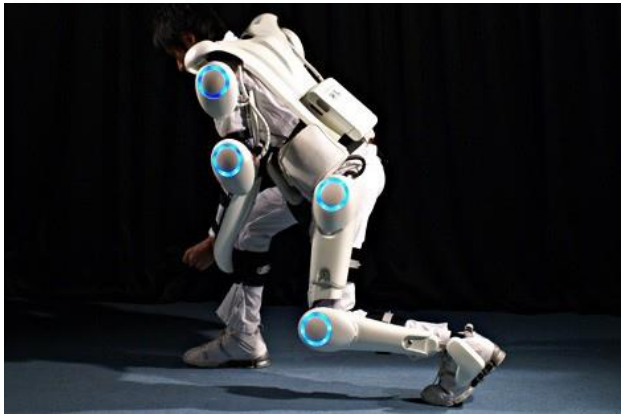
Sebastian Barrutia
PhD Candidate
Advisor: Daniel Ferris

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE


ihmc
ROBOTICS

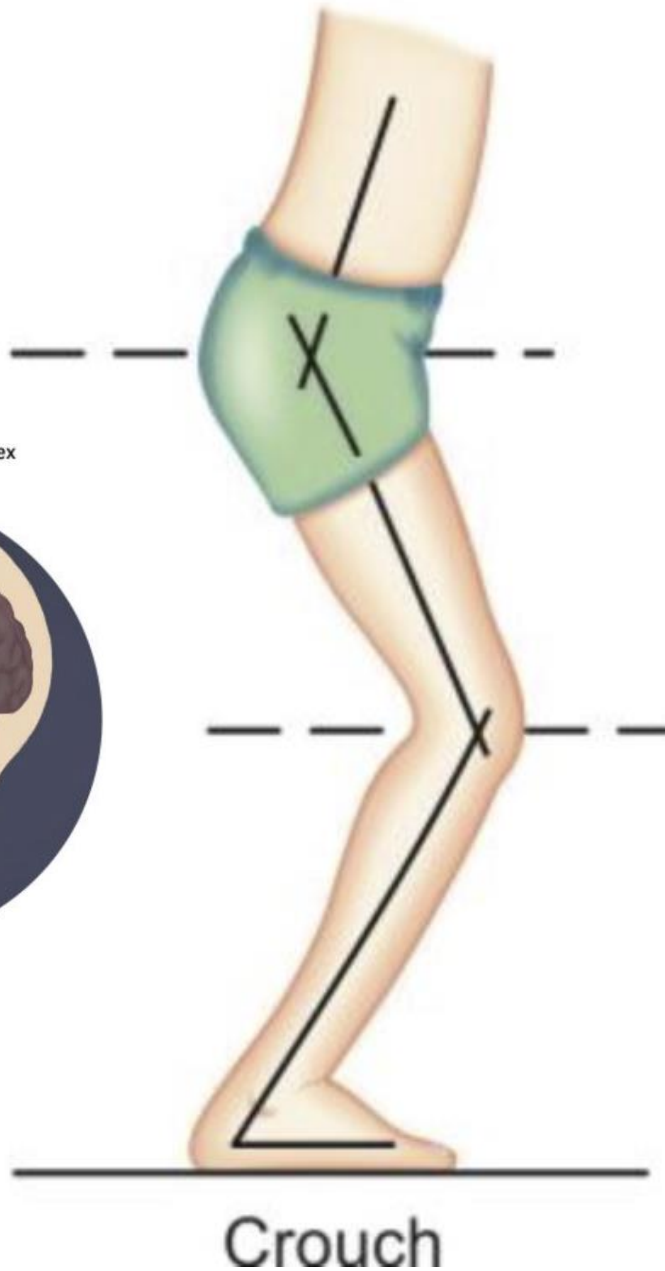



THE RESCUER
TWO GEAR MODULE

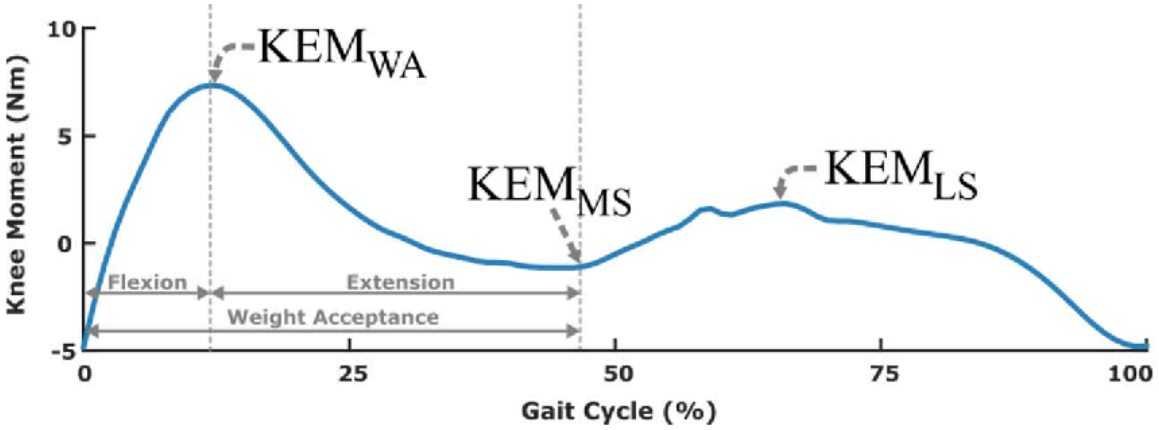


Cerebral Palsy

- 2 per 1000 births in the US
- Walking energetic cost 2-3 times higher than in other children
- Sedentary life, muscle atrophy, osteoporosis, bone deformities



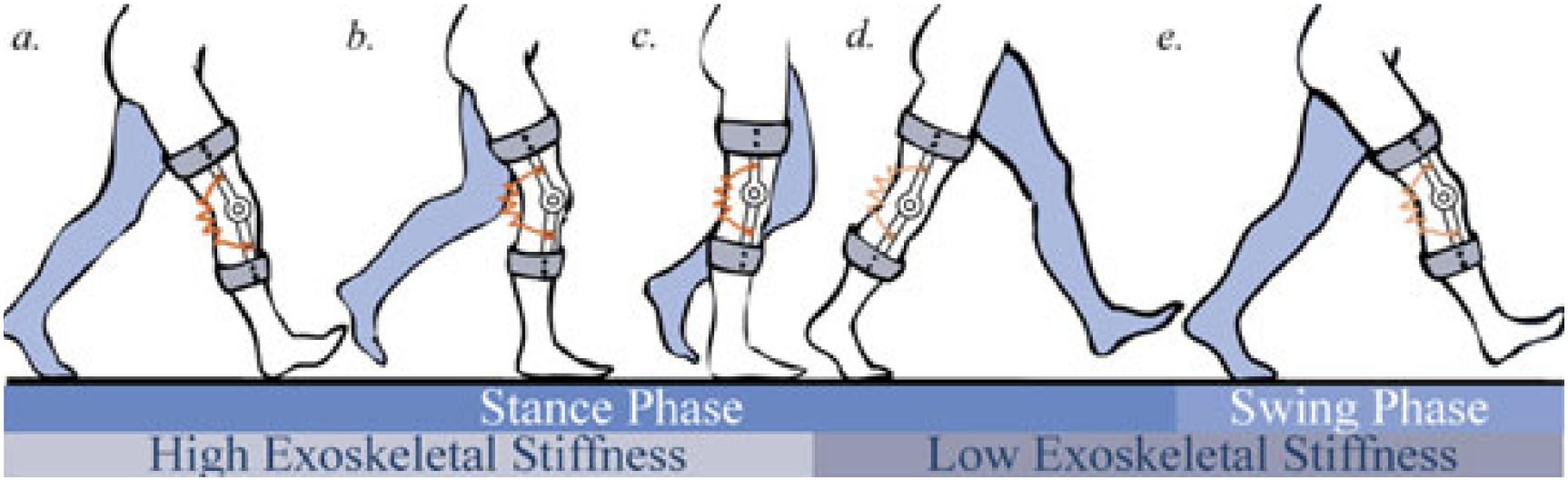
Knee Quasi-Stiffness



Lerner et al, 2016

Primary Goal

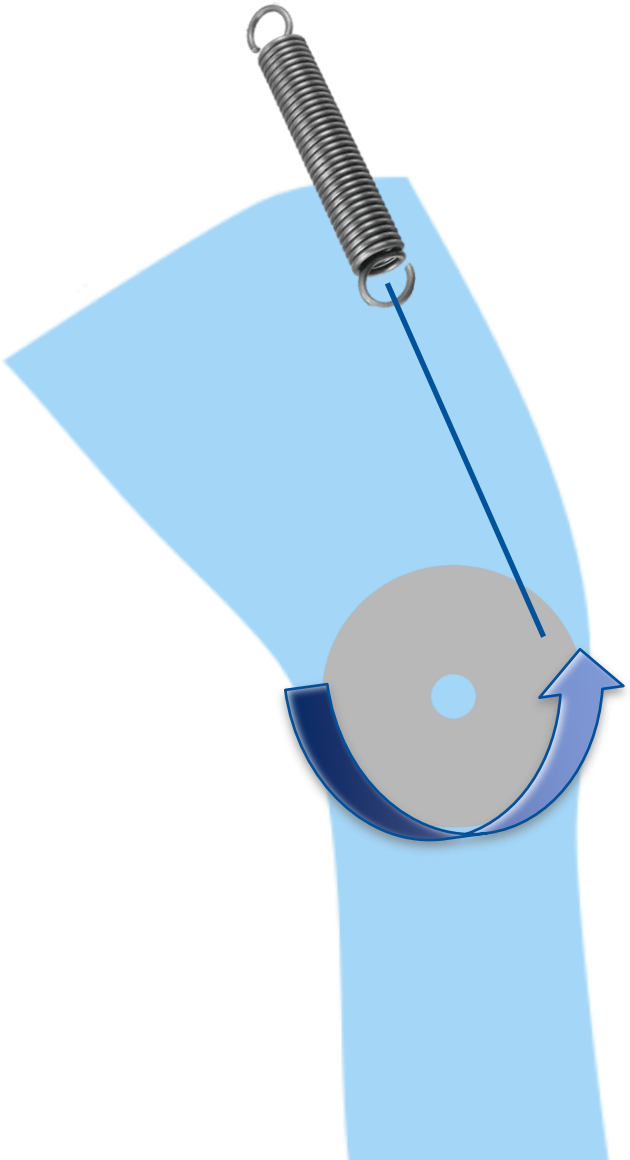
- Passive-elastic, low-weight, knee exoskeleton
  - Knee extensor moment in stance
  - No resistance in leg swing



Shamaei et al, 2014

Exoskeleton Design

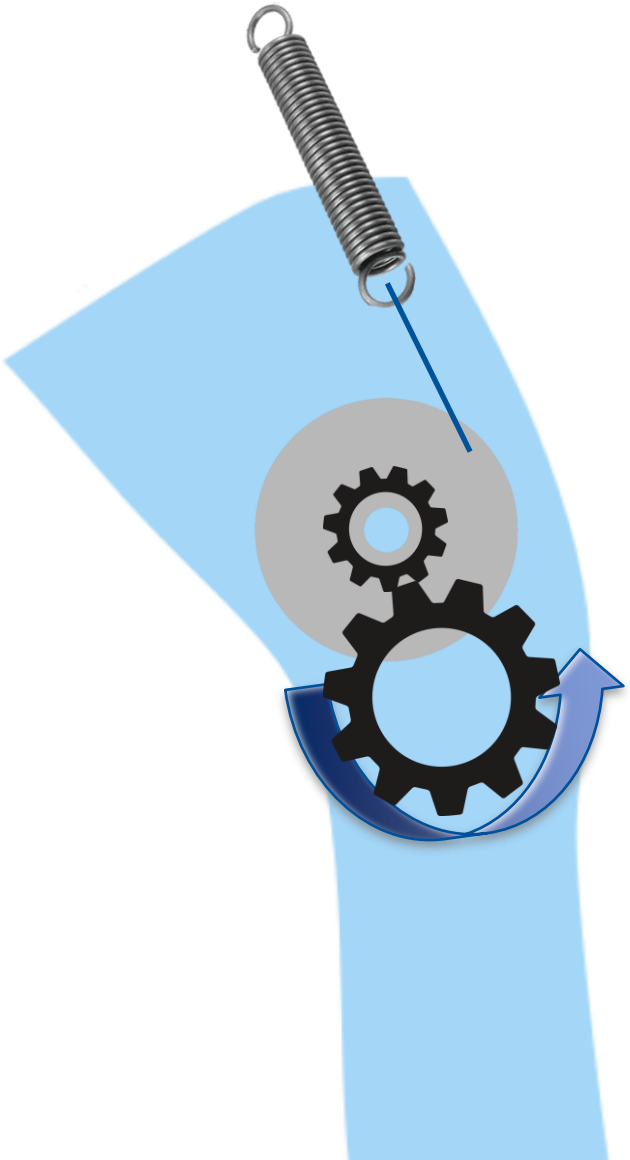
Exo Working Principle



$$k_\theta = k_l r^2$$

k_θ = knee stifness (Nm/rad)
k_l = spring stiffness (N/m)
r = pulley radius (m)

Exo Working Principle



$$k_\theta = k_l r^2 \left(\frac{T}{t}\right)^2$$

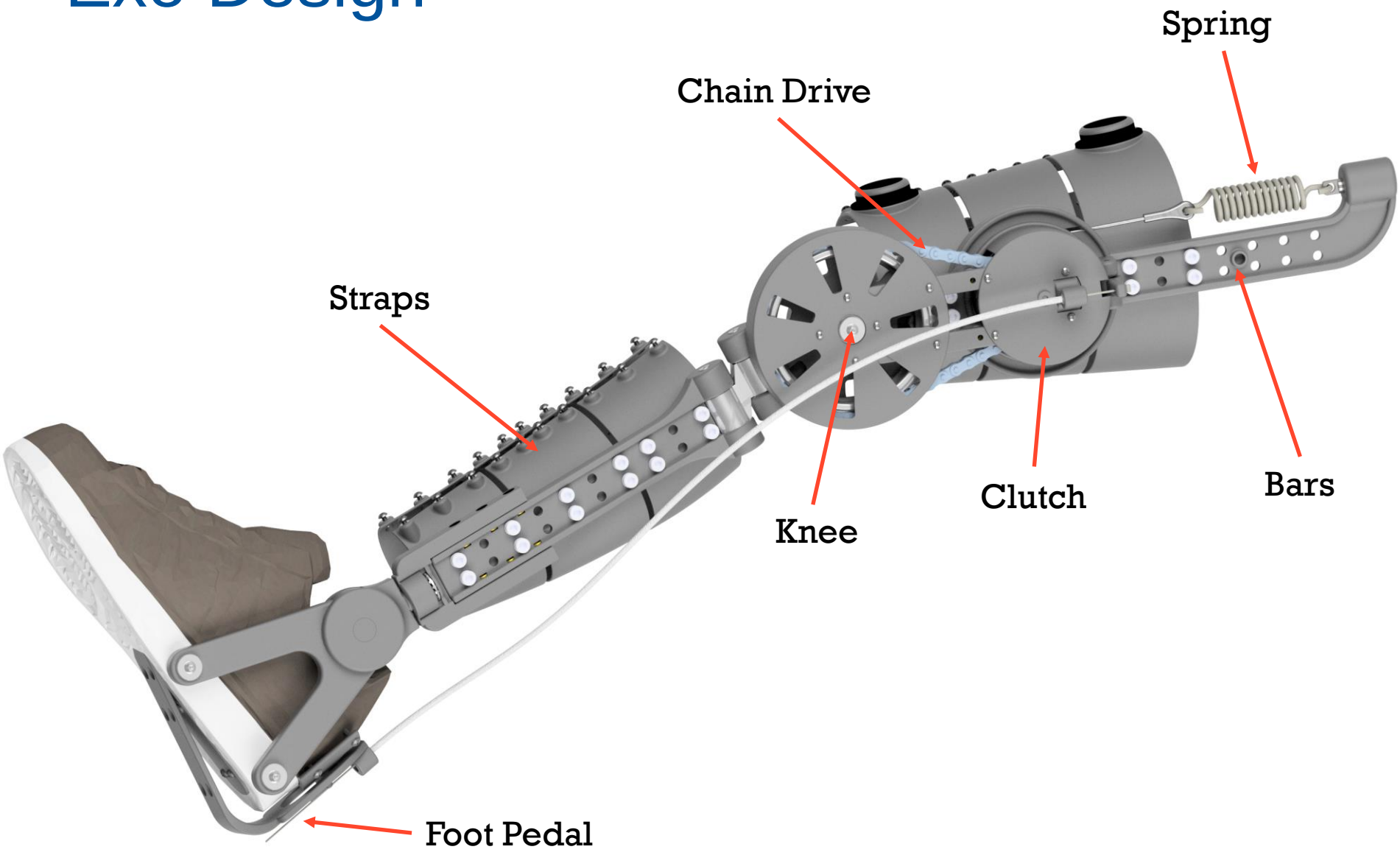
k_θ = pulley moment (Nm/rad)

k_l = spring stiffness (N/m)

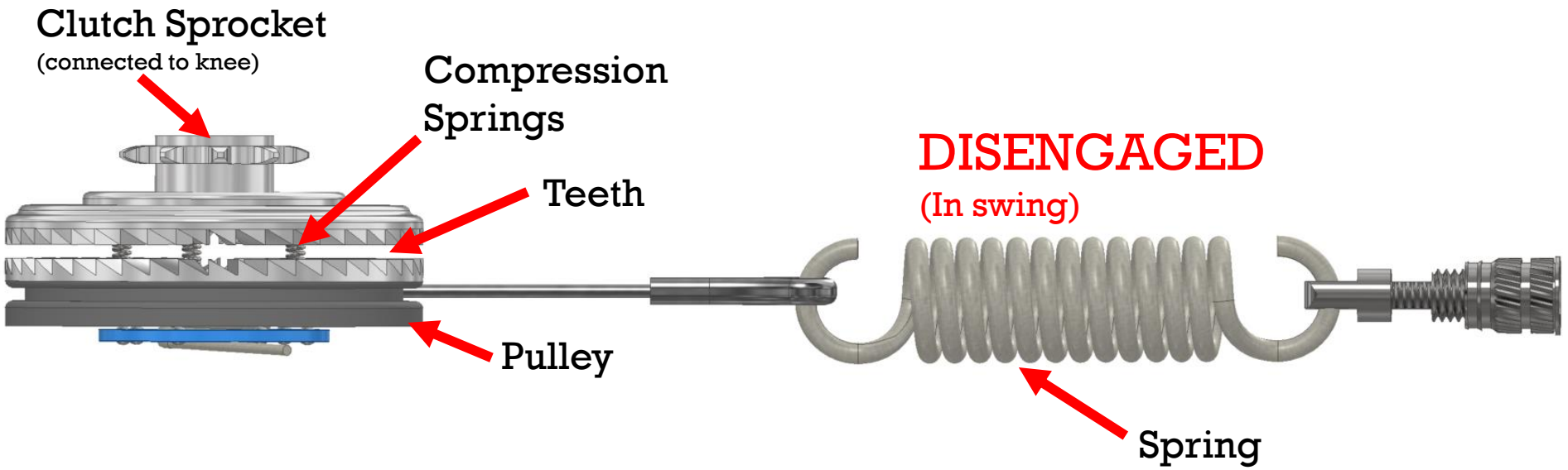
r = pulley radius (m)

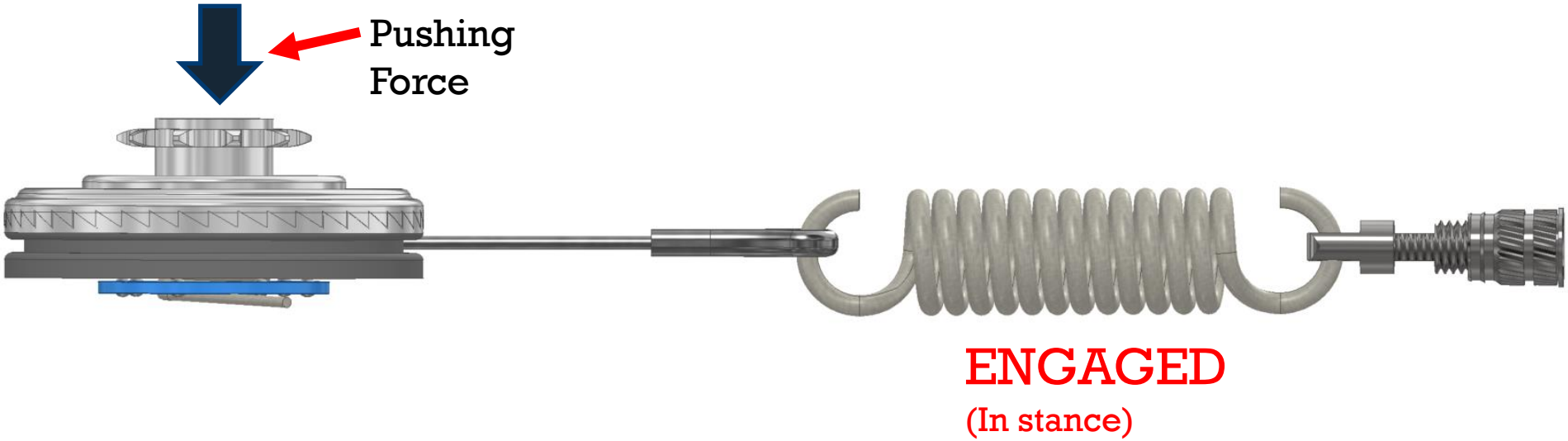
$\frac{T}{t}$ = transmission ratio

Exo Design

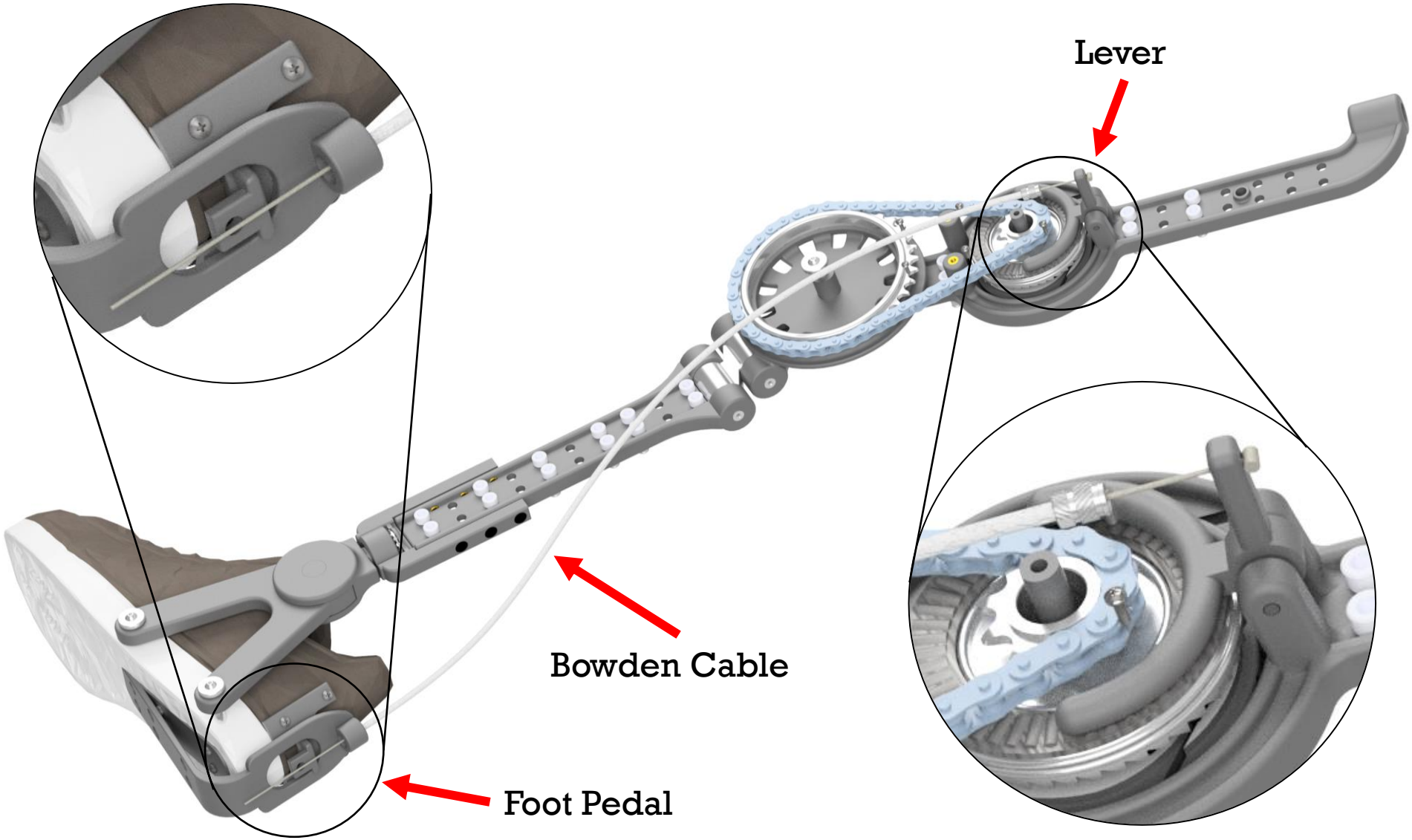


Exo Clutch


Clutch Sprocket
(connected to knee)
Compression Springs
Teeth
Pulley
DISENGAGED
(In swing)
Spring


Pushing Force
ENGAGED
(In stance)

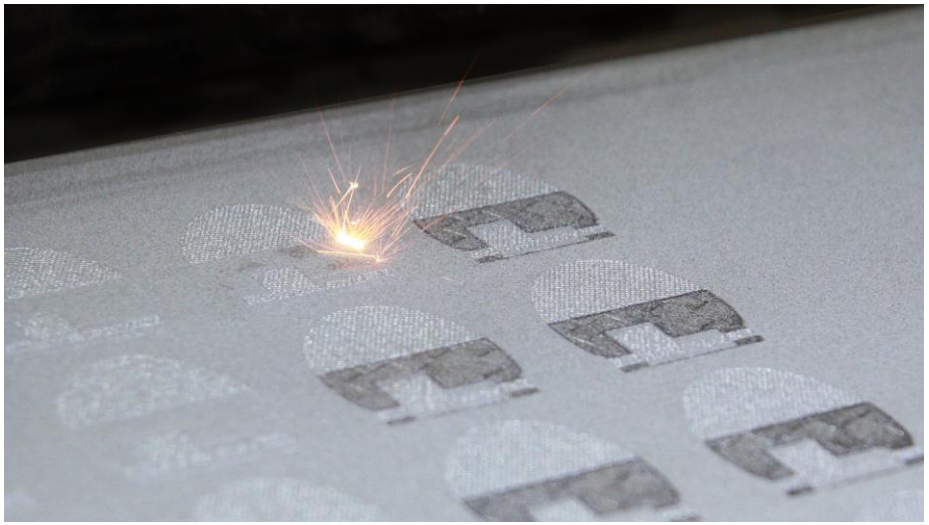
Exo Bowden Cable



Materials

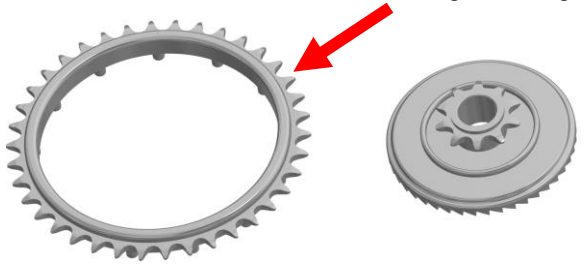
Composite 3D Printing

Metal 3D Printing



Carbon Fiber

Aluminum



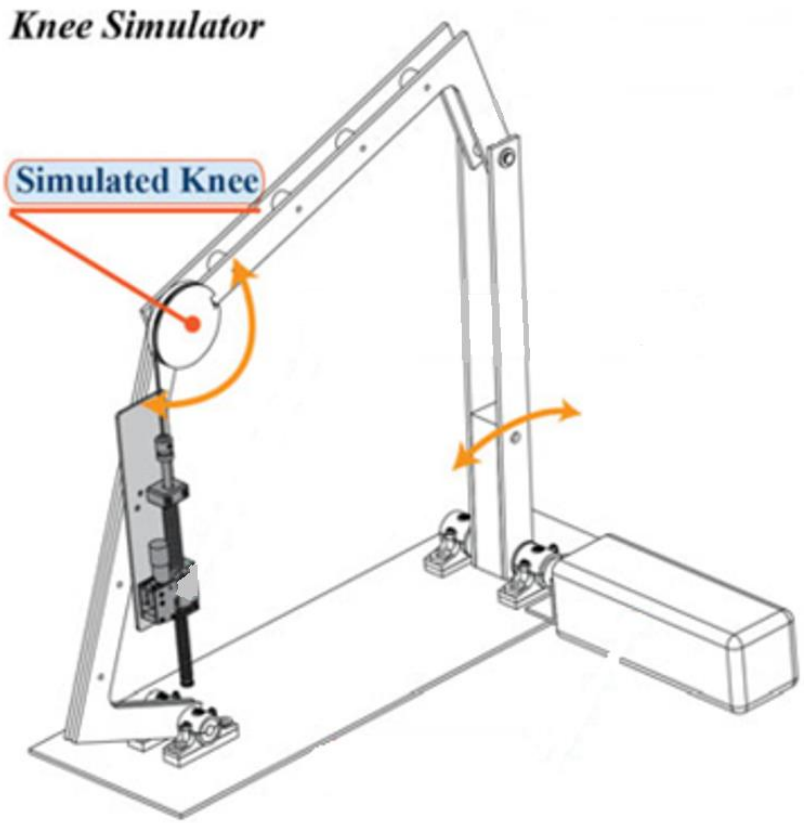
- Entirely mechanical
  - Extensor moment ~ Δ knee flexion
    $$\boldsymbol{M = k_\theta(\Delta\theta)}$$
- Customizable
  - Spring Stiffness
  - Strap/exo size
- Lightweight
  - 2.7 kg (6 lbs) for both legs

Exoskeleton Characterization

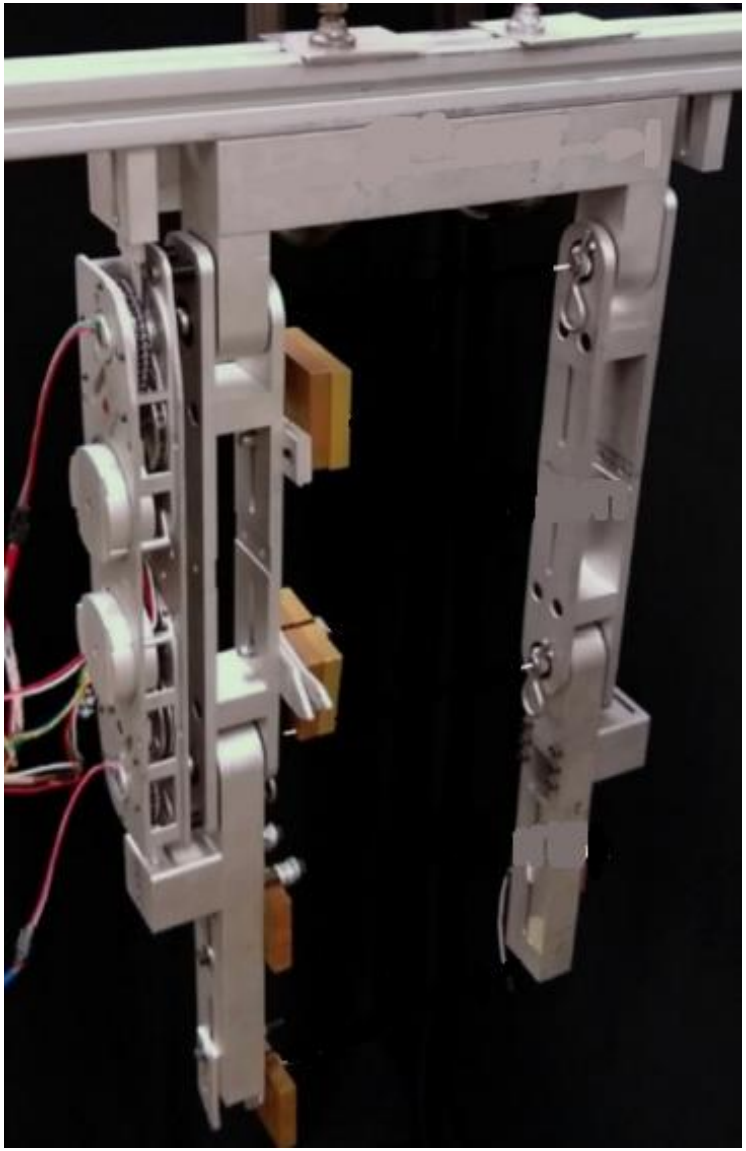
Mechanical Phantom Testing Advantages

- Time savings
- Lack of confounding factors
  - Subject heterogeneity
  - Known internal joint moments
- Lack of safety concerns

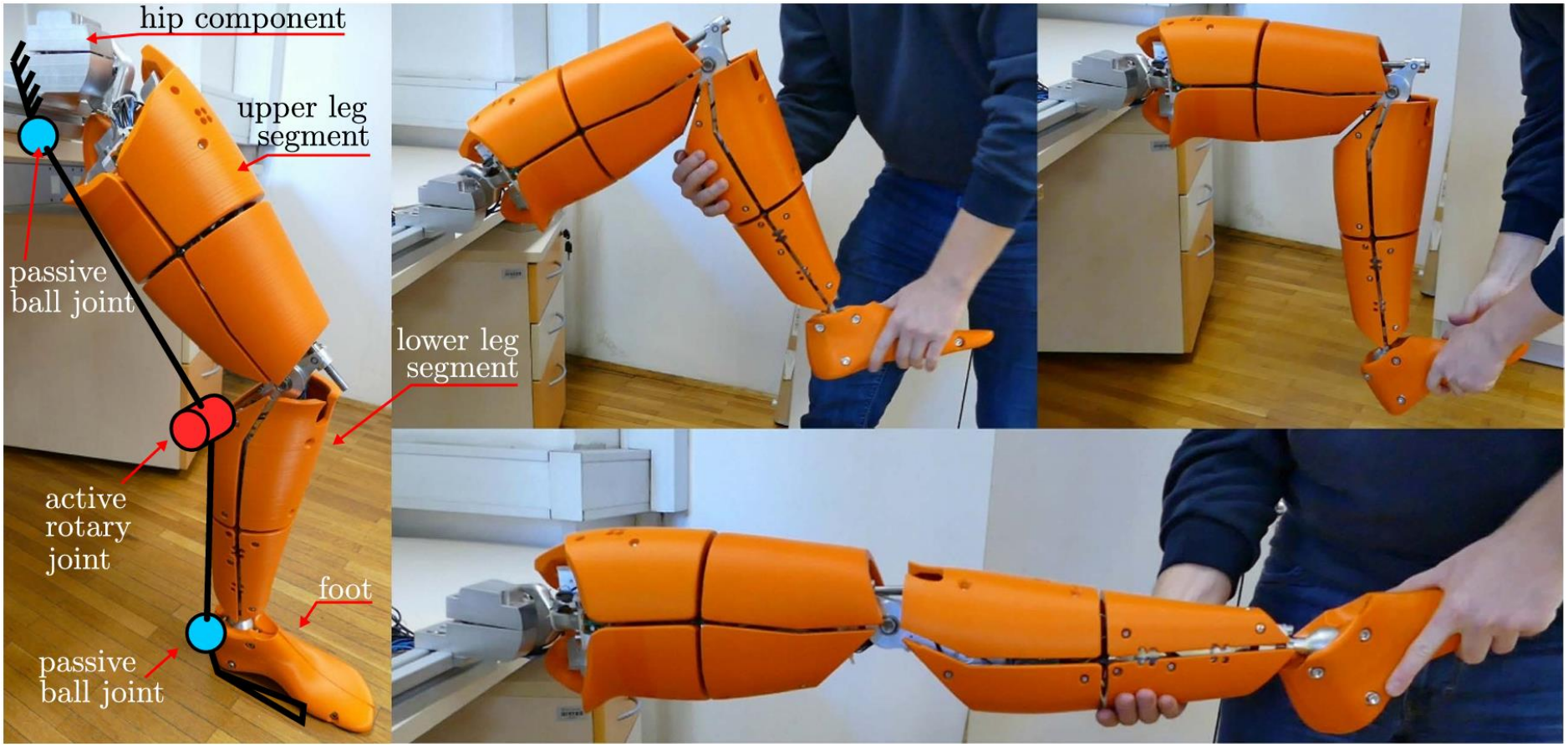
Mechanical Phantoms

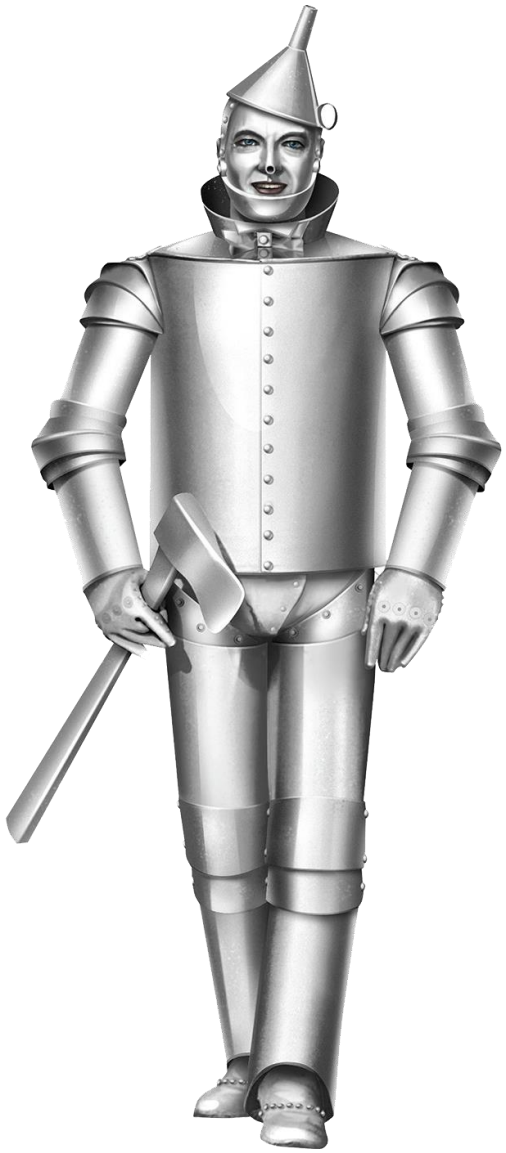


Shamaei et al, 2014



Goo et al, 2020


hip component
upper leg segment
passive ball joint
lower leg segment
active rotary joint
foot
passive ball joint

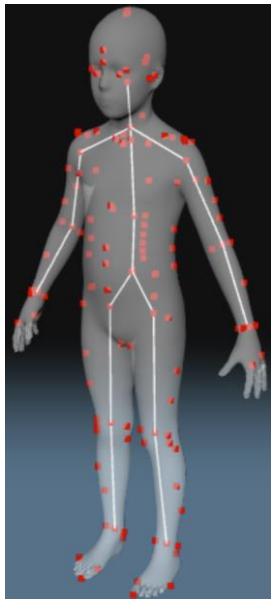


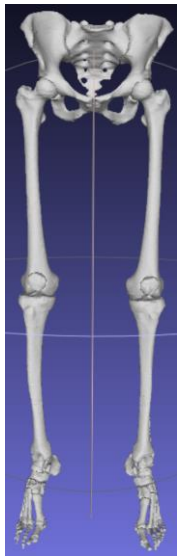
Humans are squishy!

Ballistic Gel Phantoms

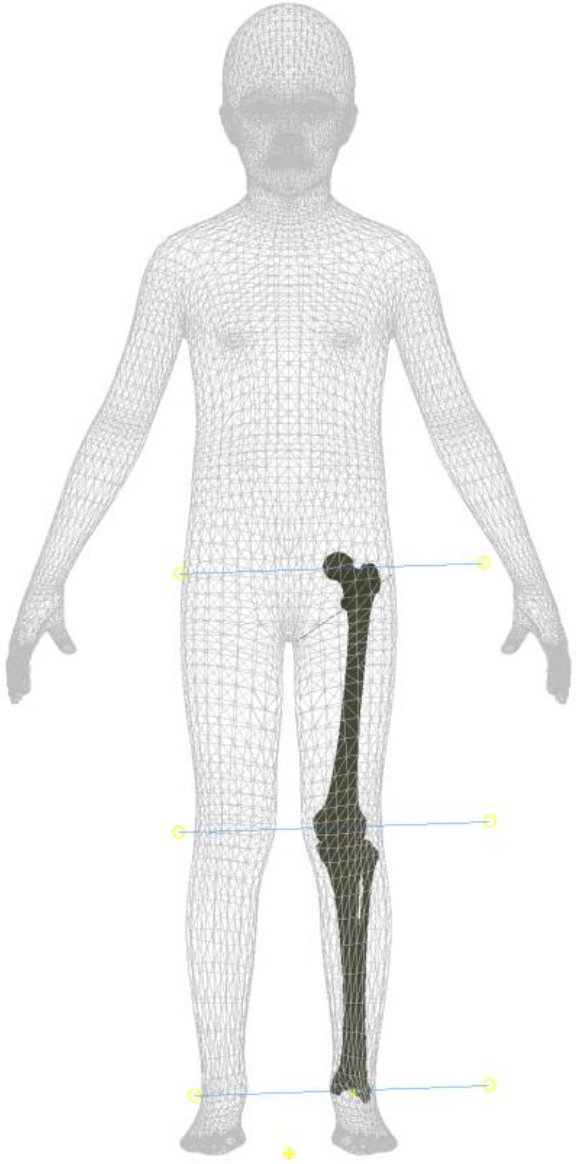
a

Model





Linear scaling to fit model landmarks



Construction

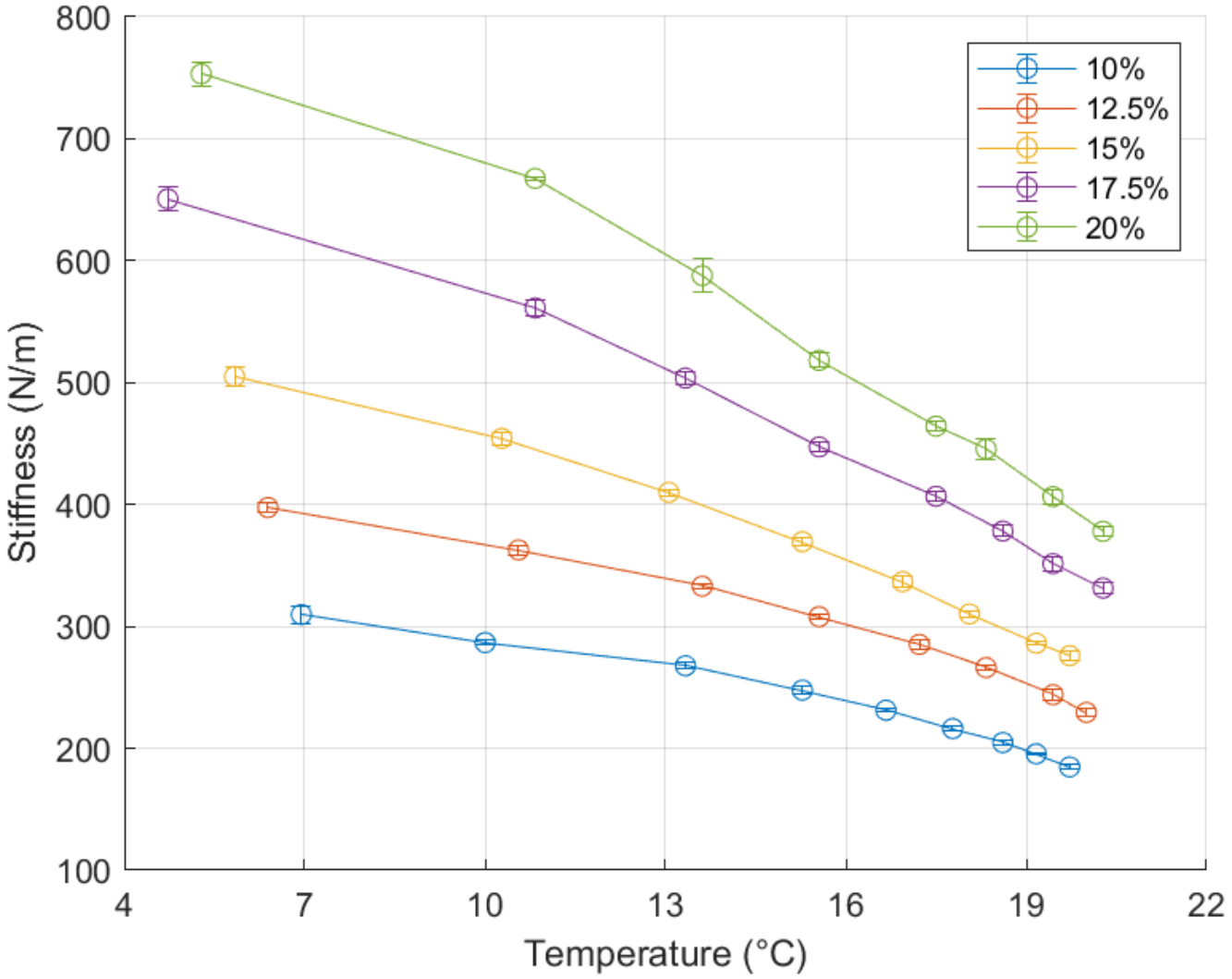
- Ballistics gel simulates soft-tissue deformation
- Bones 3D printed and reinforced with carbon fiber

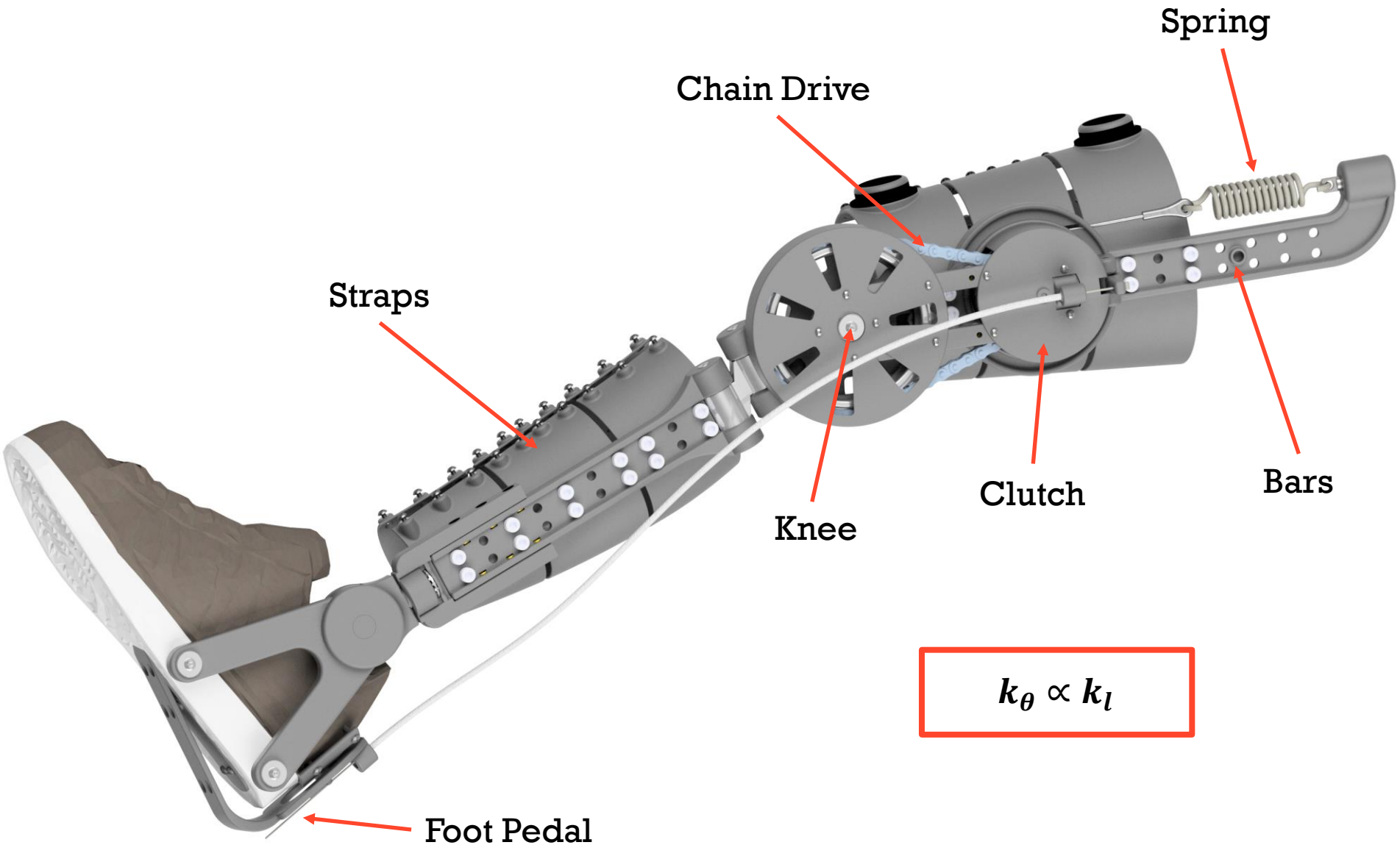
Inv. Dynamics Instrumentation

- Load cells at the foot measure vertical ground reaction forces
- Phantom and exoskeleton passive markers

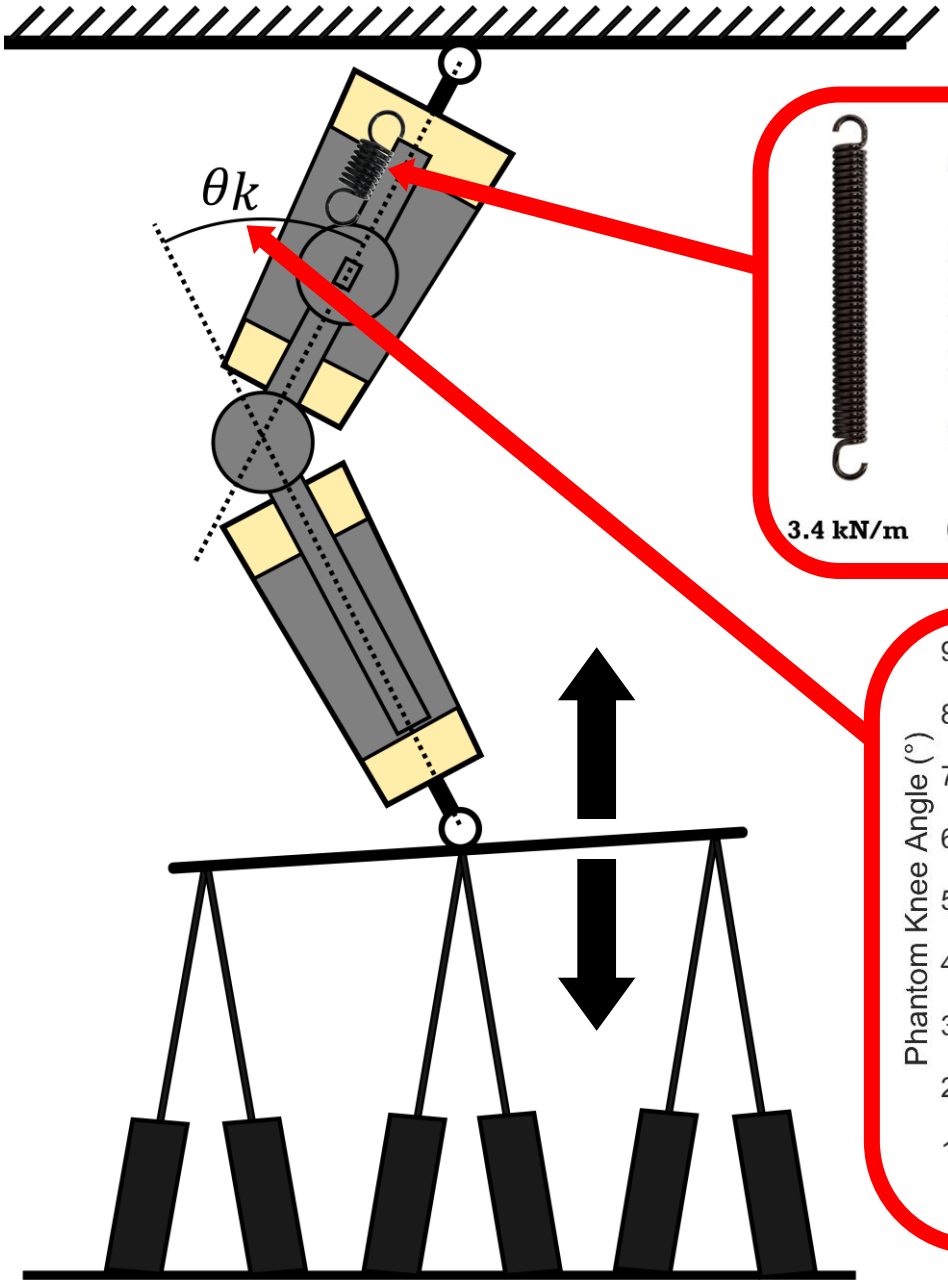

Compliant ballistic gel
Motion capture markers
Stiff, carbon fiber reinforced bones
Load Cells

Ballistic Gel Stiffness

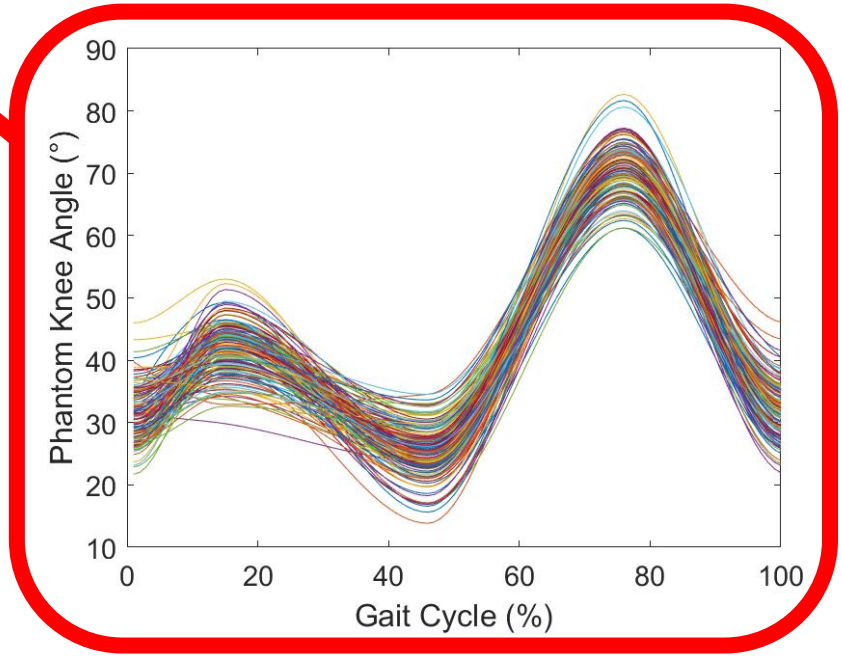




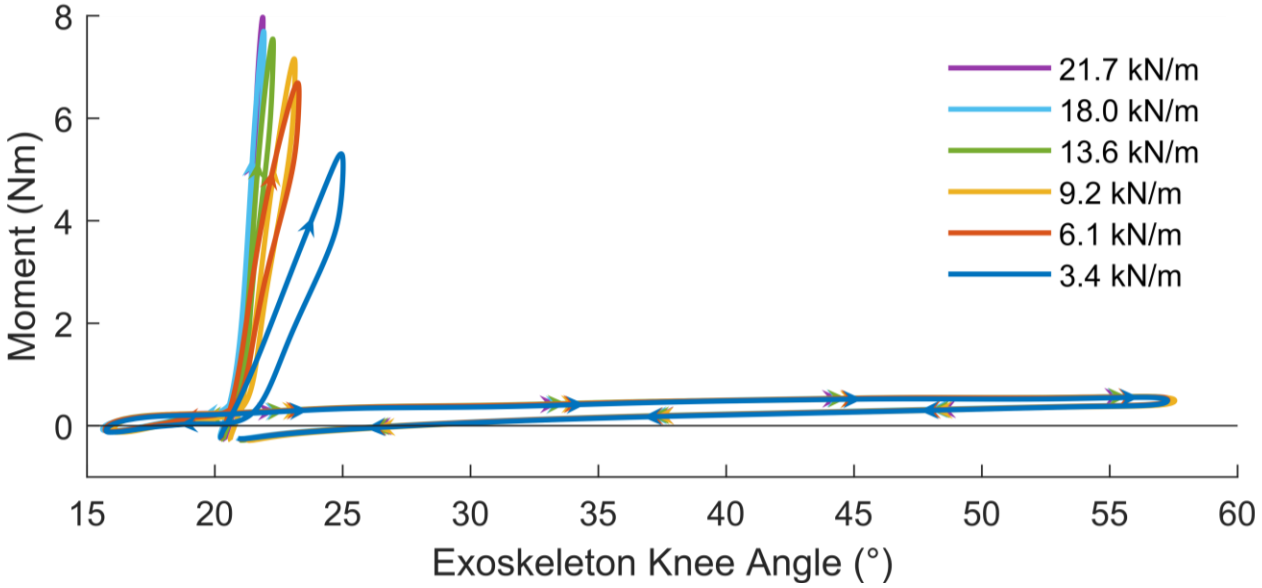
$$k_\theta \propto k_l$$

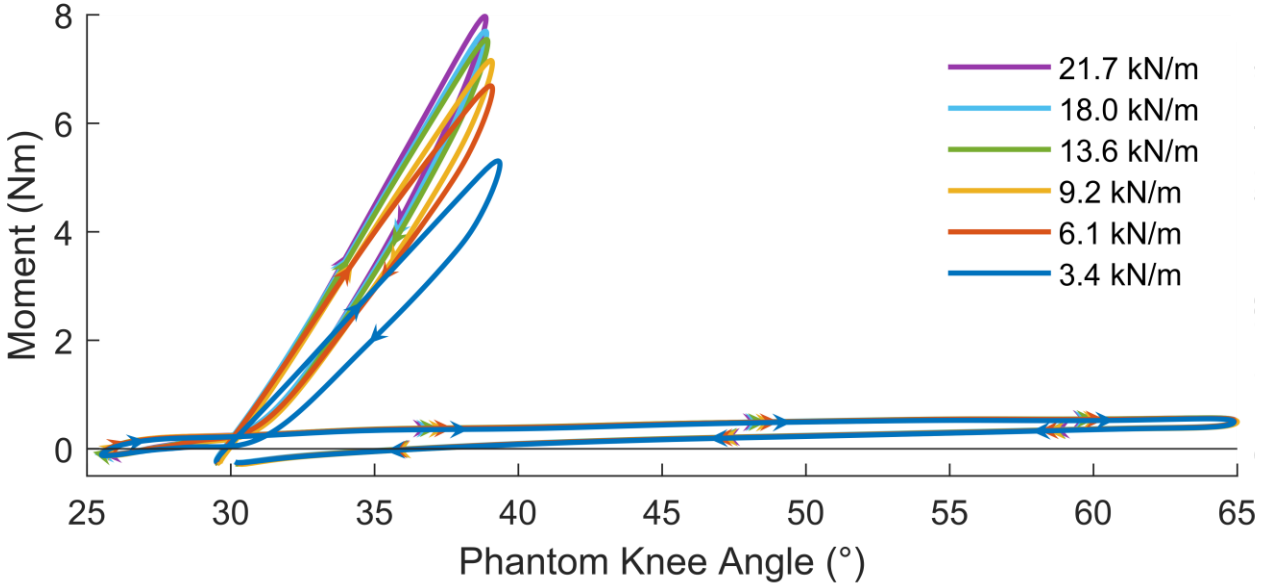

θk

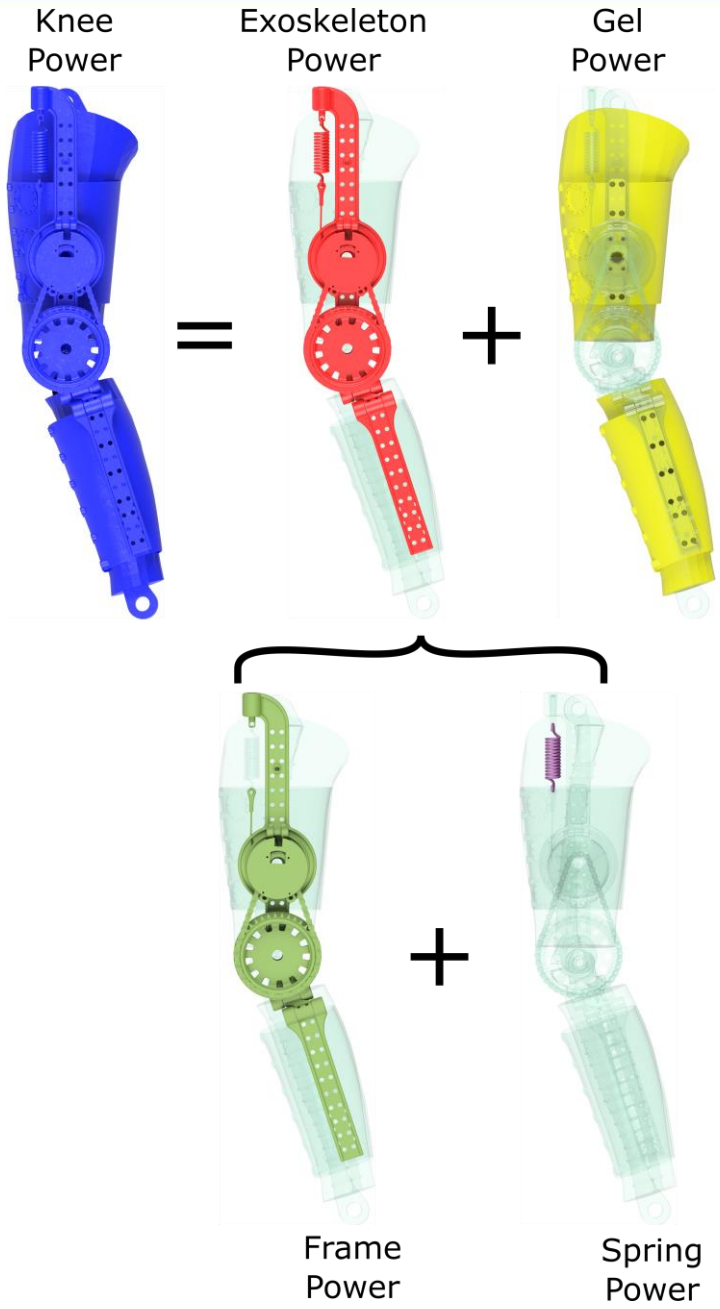

3.4 kN/m
6.1 kN/m
9.2 kN/m
13.6 kN/m
18.0 kN/m
21.7 kN/m


Phantom Knee Angle (°)
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
Gait Cycle (%)


BOA
BOA
BOA
Symétrie

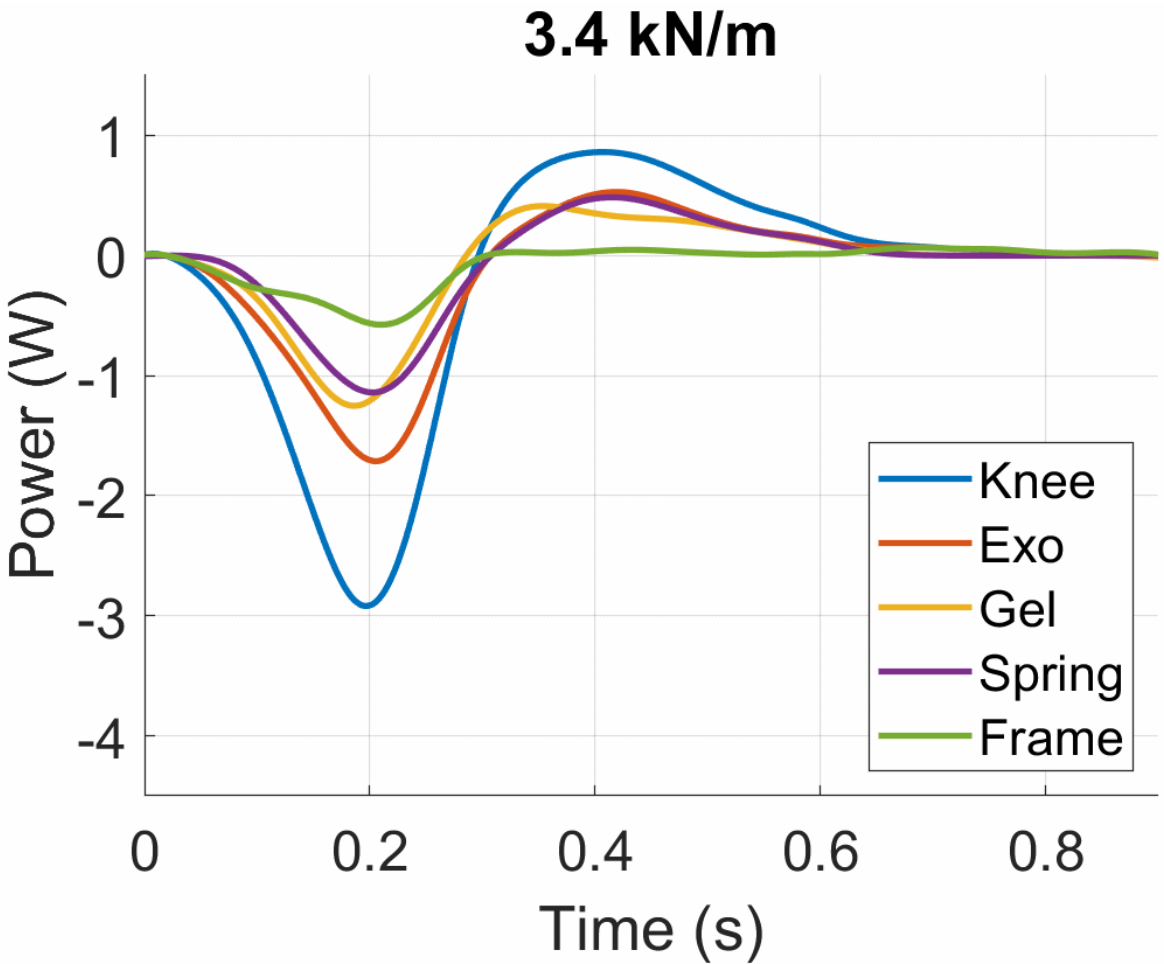

Moment (Nm)
Exoskeleton Knee Angle (°)
21.7 kN/m
18.0 kN/m
13.6 kN/m
9.2 kN/m
6.1 kN/m
3.4 kN/m

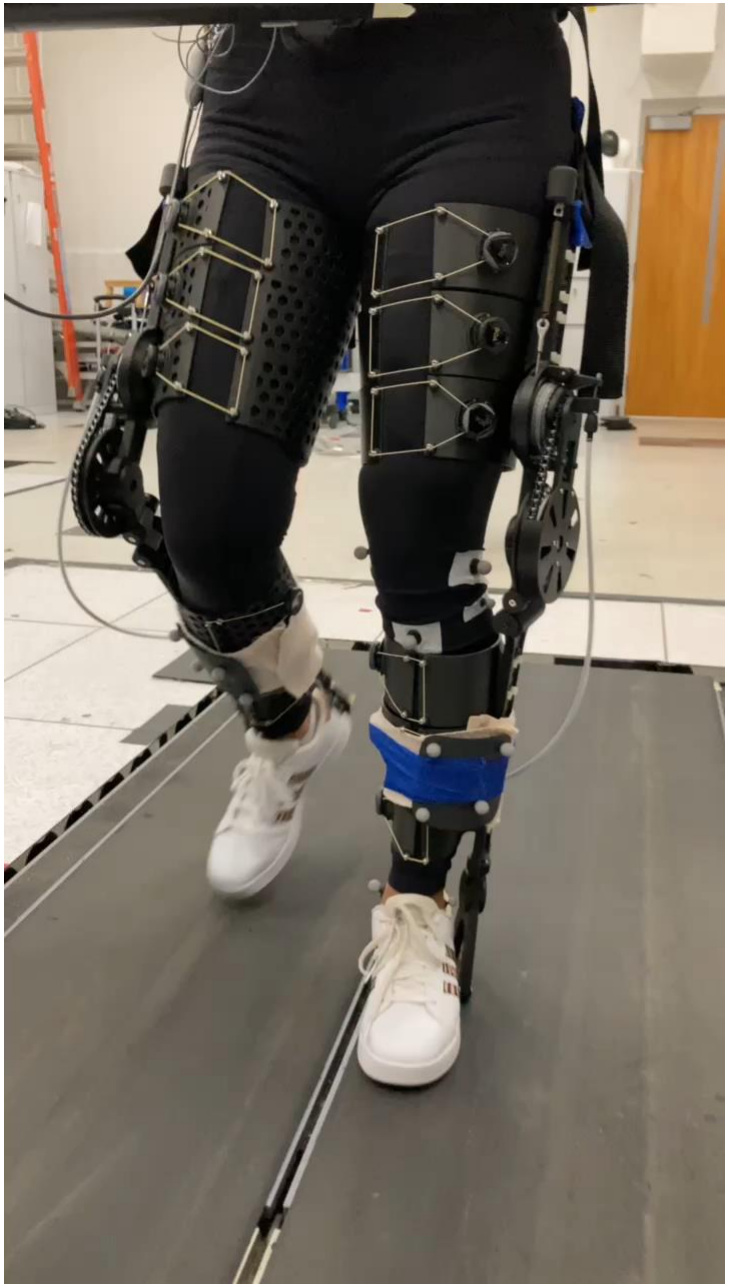

Moment (Nm)
Phantom Knee Angle (°)
21.7 kN/m
18.0 kN/m
13.6 kN/m
9.2 kN/m
6.1 kN/m
3.4 kN/m


Knee Power
Exoskeleton Power
Gel Power
=
+
+
Frame Power
Spring Power

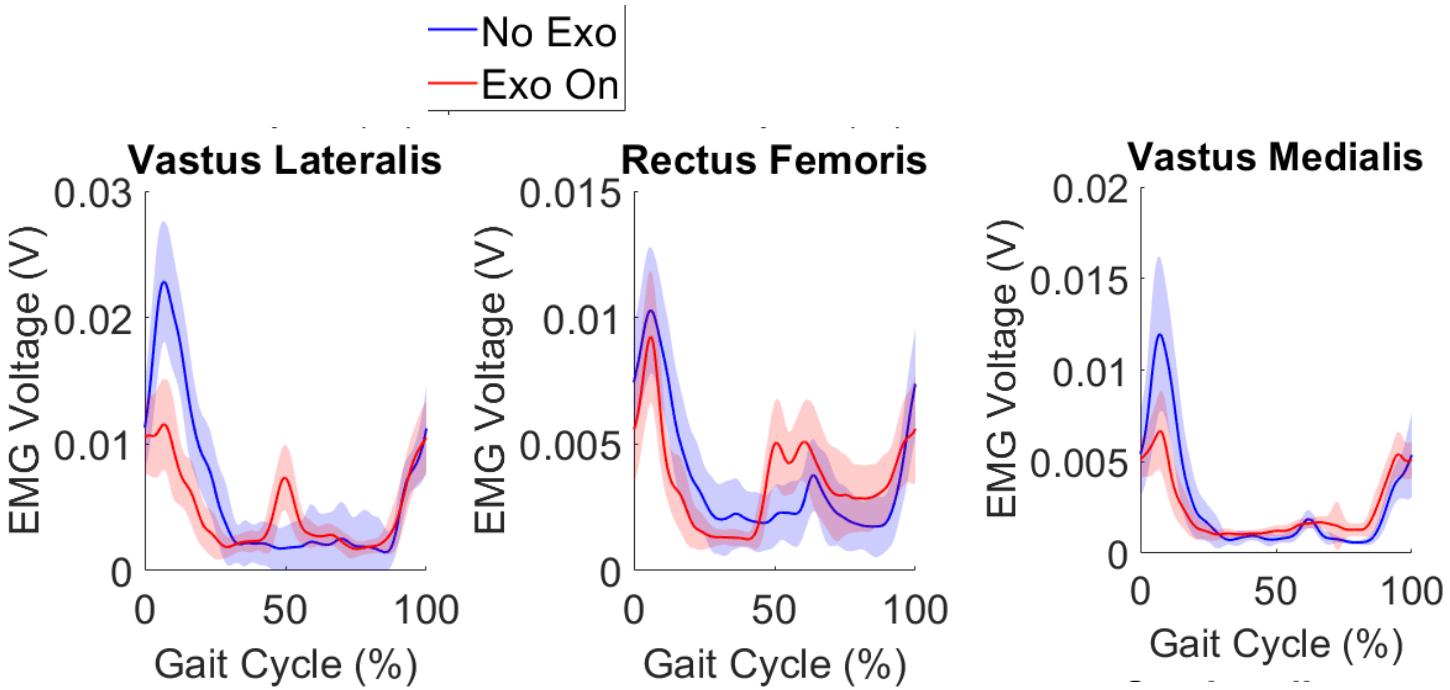
Knee Power = Exo Power + Gel Power

Exo Power = Spring Power + Frame Power





Muscle Activity



Acknowledgements

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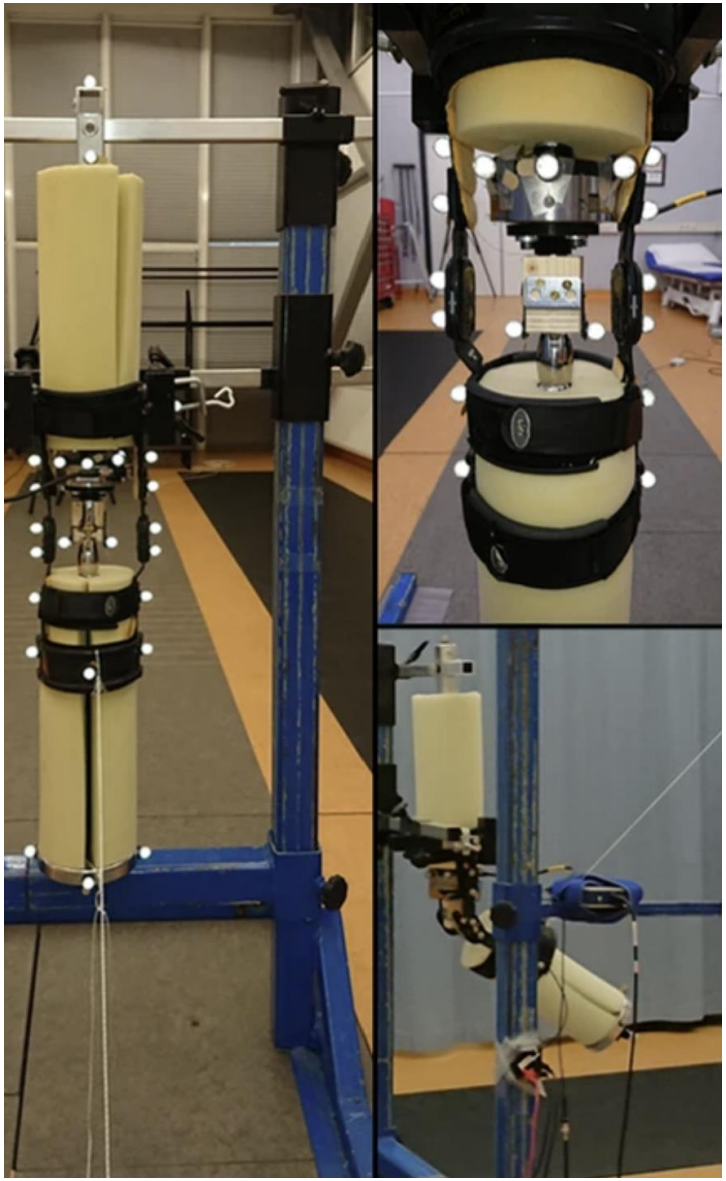
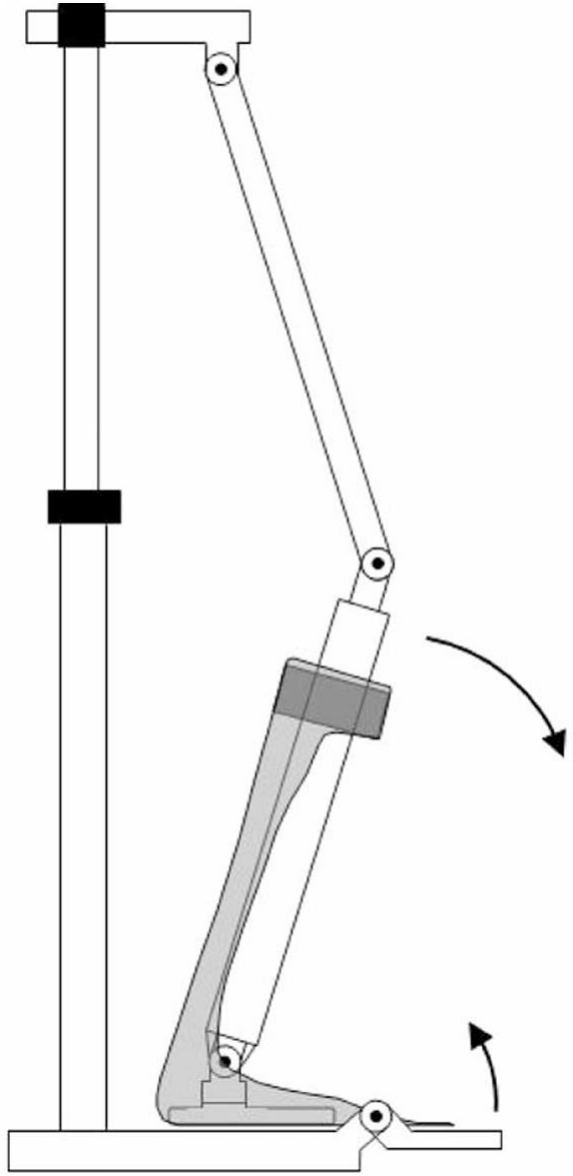
  - Leo Claire & Robert Adenbaum Foundation
  - NIH T32 Neuromuscular Plasticity Program

HNL UF HUMAN NEUROMECHANICS LAB

- Doctoral Committee
  - Daniel Ferris
  - Jennifer Nichols
  - Scott Banks
  - Dorian Rose





Cerebral Palsy Exoskeletons

Mataki et al, 2018

Orekhov et al, 2020

Lerner et al, 2017

Chen et al, 2021