Design of a Soft, Passive Wearable Ankle Device

Team 4

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Introduction

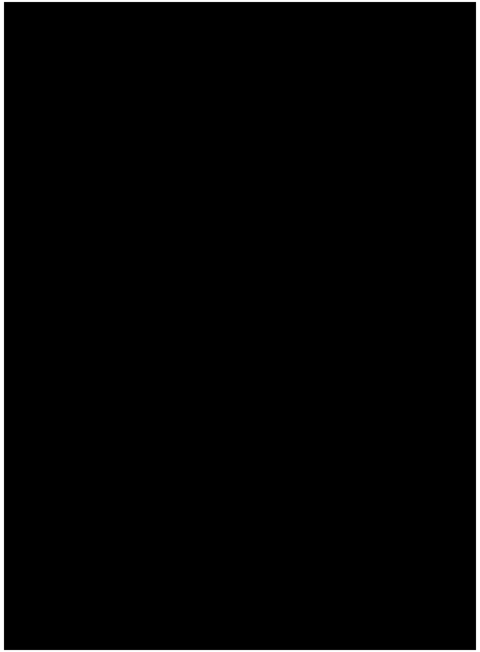
- How can we design a **low cost, soft, wearable ankle device** that is actuated passively by the human user's weight to **reduce human effort required while walking**?

Introduction — Bio-inspiration

- Human skeletal muscle
  - Pneumatic actuators can achieve similar output

Human Muscle

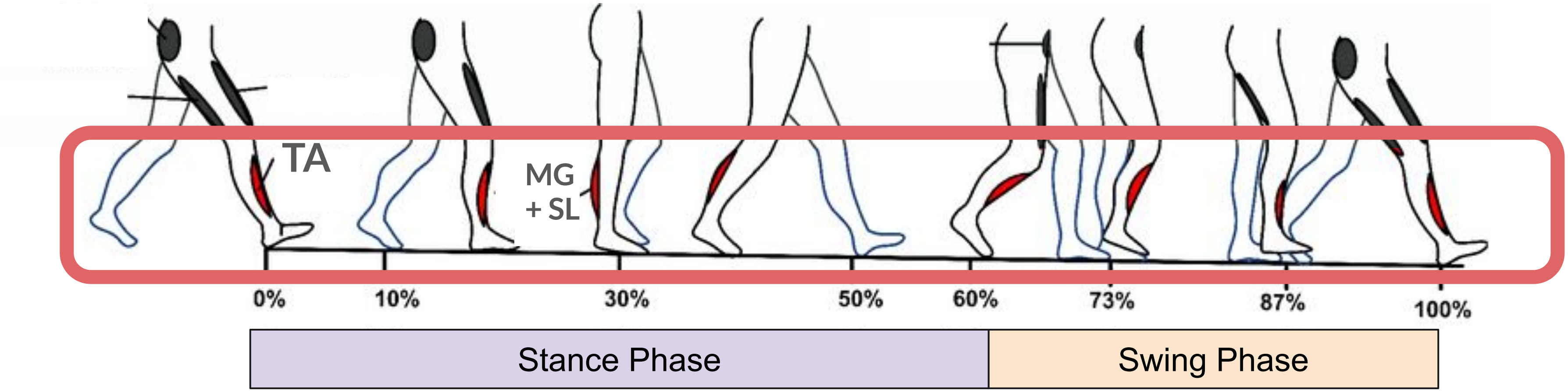
McKibben Air Muscle



Our Pneumatic Actuator

Introduction — Human Muscles during Gait

- When is a human putting in muscle effort into while walking?



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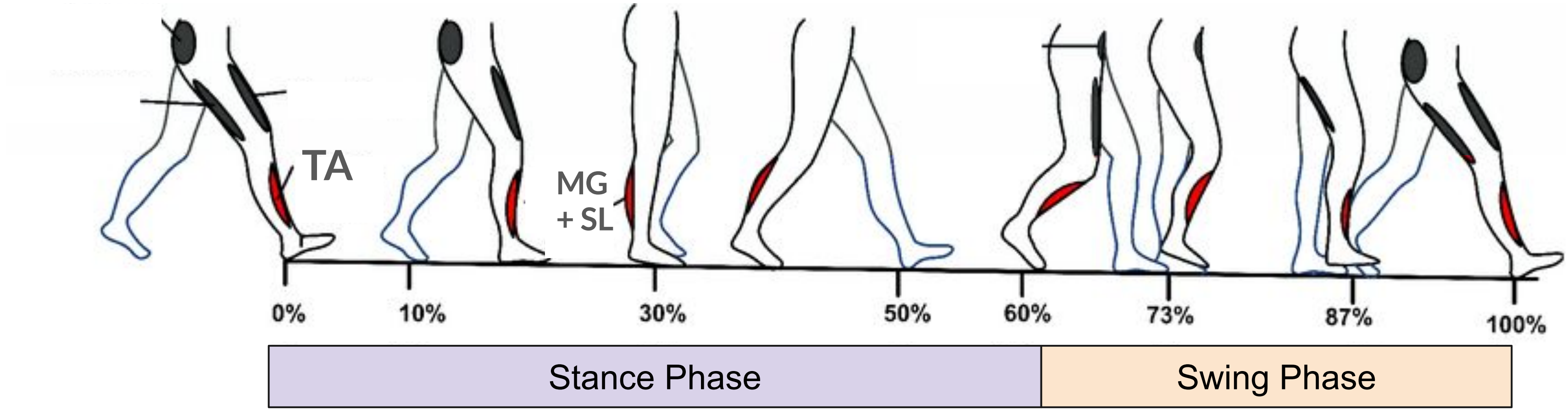
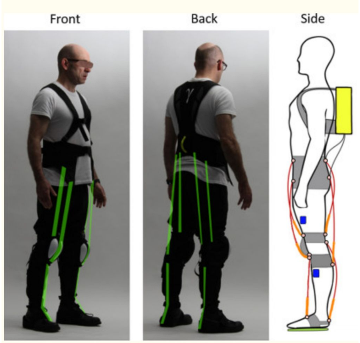


Introduction — Devices Assisting in Walking

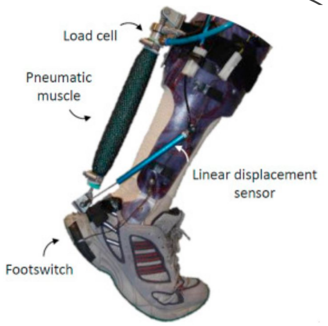
Non-Robotic Devices

Foot Drop AFOs

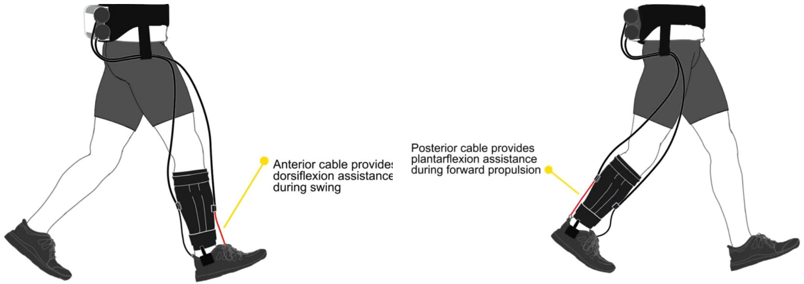
Robotic Devices (State of the Art)



Lower Limb Exoskeleton [1]



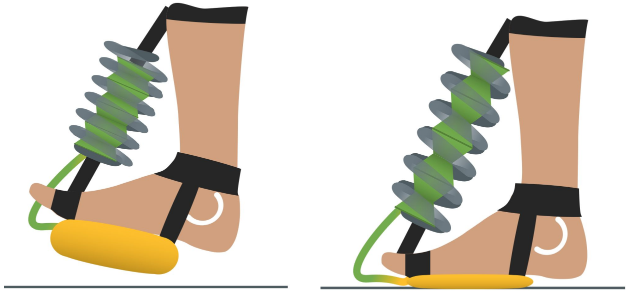
Plantar-flexion Assistive Exosuit [2]



ReWalk Robotics- ReStore Exosuit [3]

Our Device

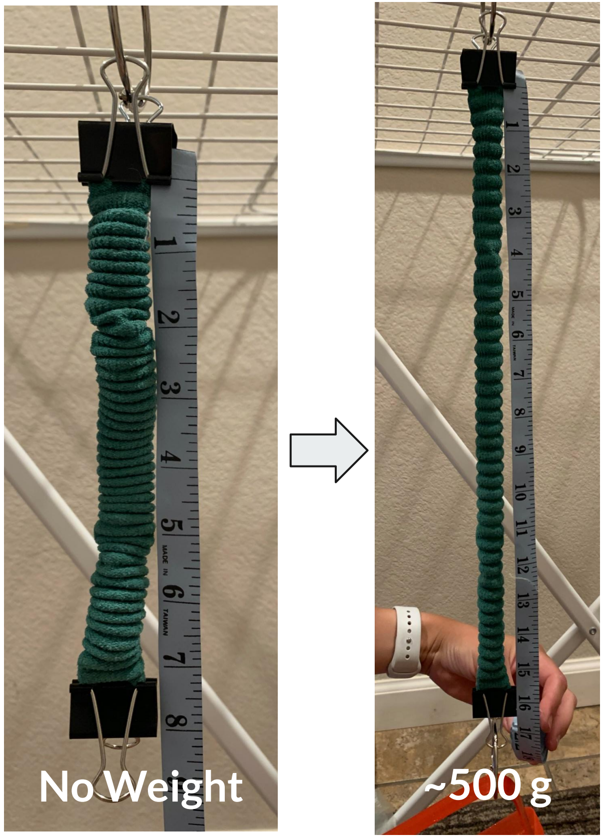
- Instead of electronics/sensors, we propose to use a **closed pneumatic system** to identify gait events and turn on and off our **pneumatic muscle**
    - Apply robotics research on pneumatic muscles to a low cost device



Methods — Actuator Modeling

- Model our pneumatic muscle to make design decisions

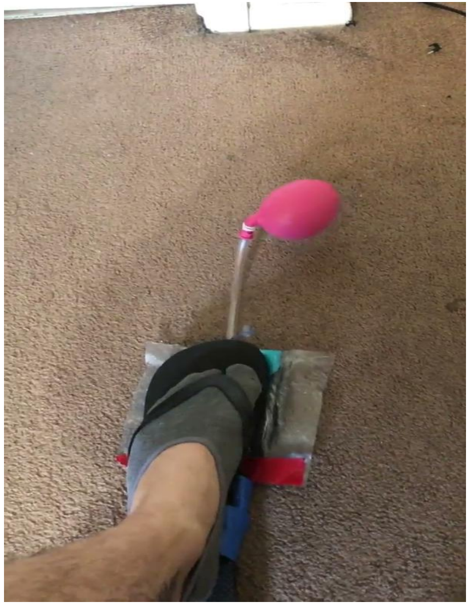
Volume Measurements



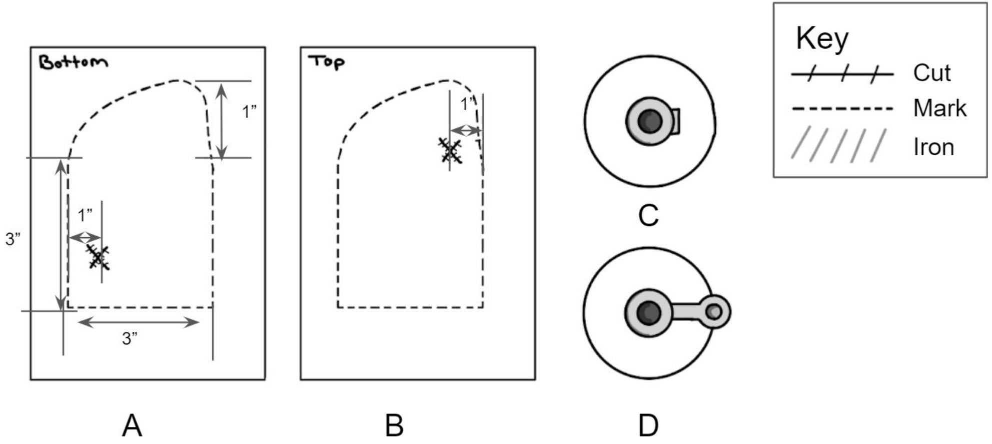
Stiffness Characterization

Methods — Reservoir Design Iterations

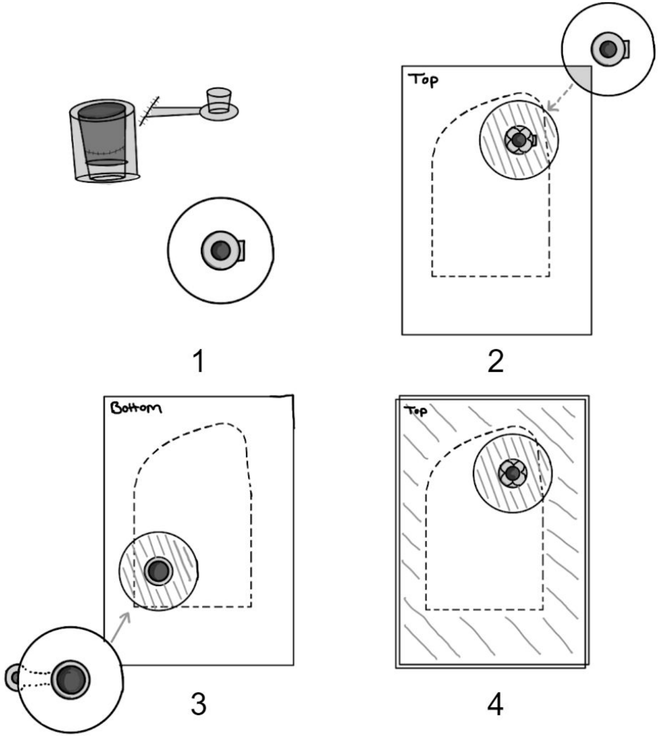
- Used volume measurements required for actuator to **choose reservoir size**
- Reservoir placement based on muscle activation

Methods — Reservoir Design Final

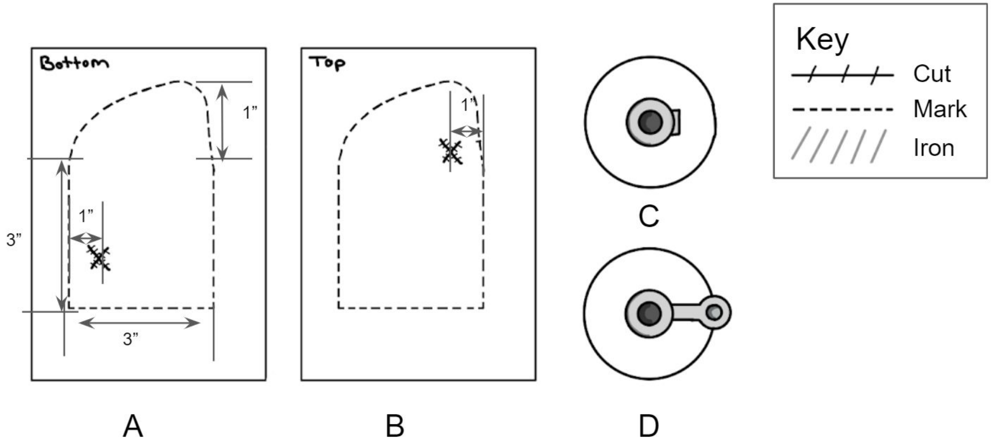


Parts of the Assembly

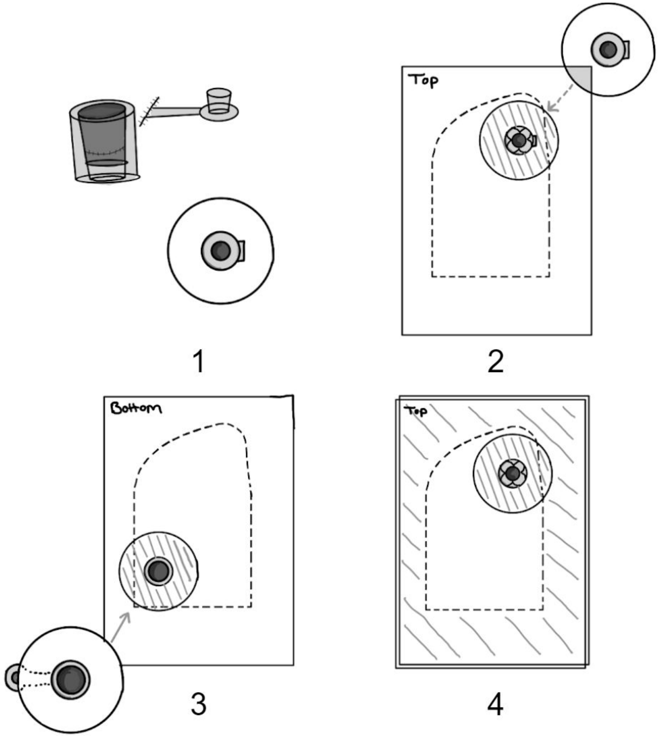


Manufacturing Steps

Parts of the Assembly

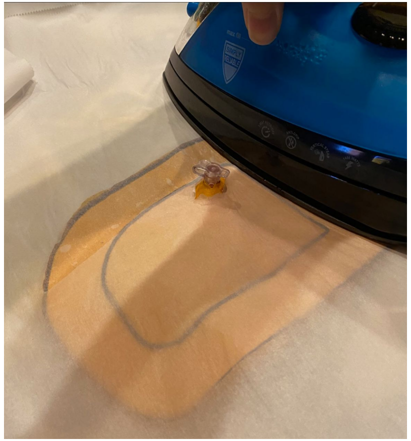


Manufacturing Steps



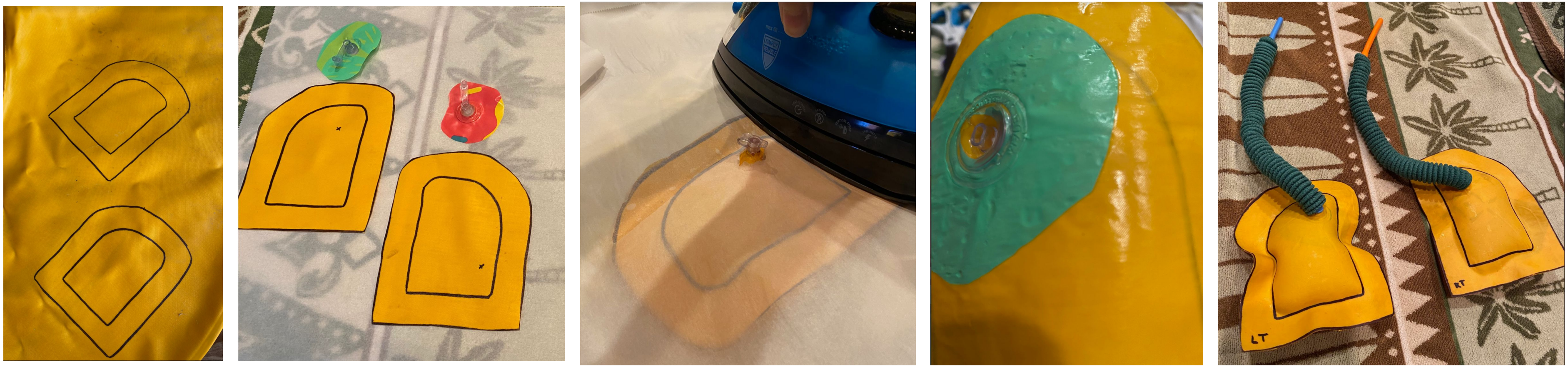
Methods — Reservoir Design Final





Outline → **Cut** → **Iron** → **Assemble**

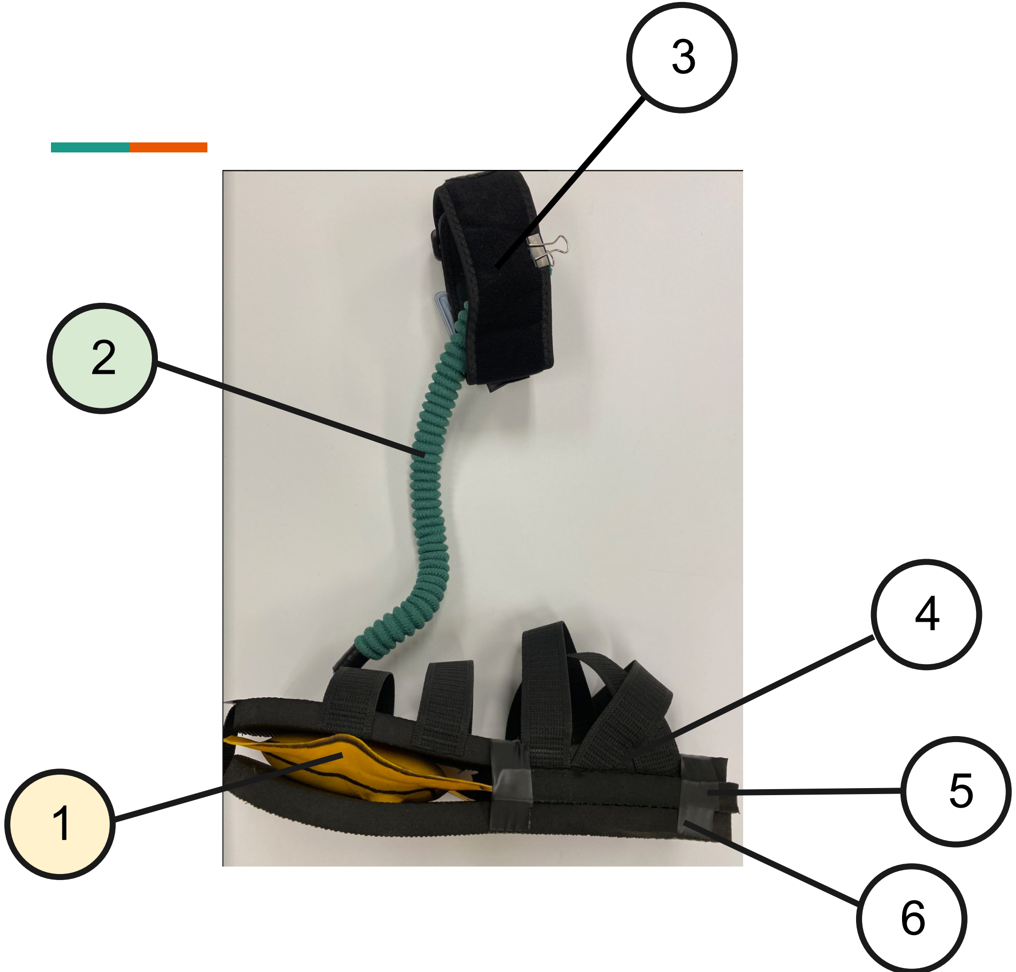
1.5 hrs of Manufacturing Time



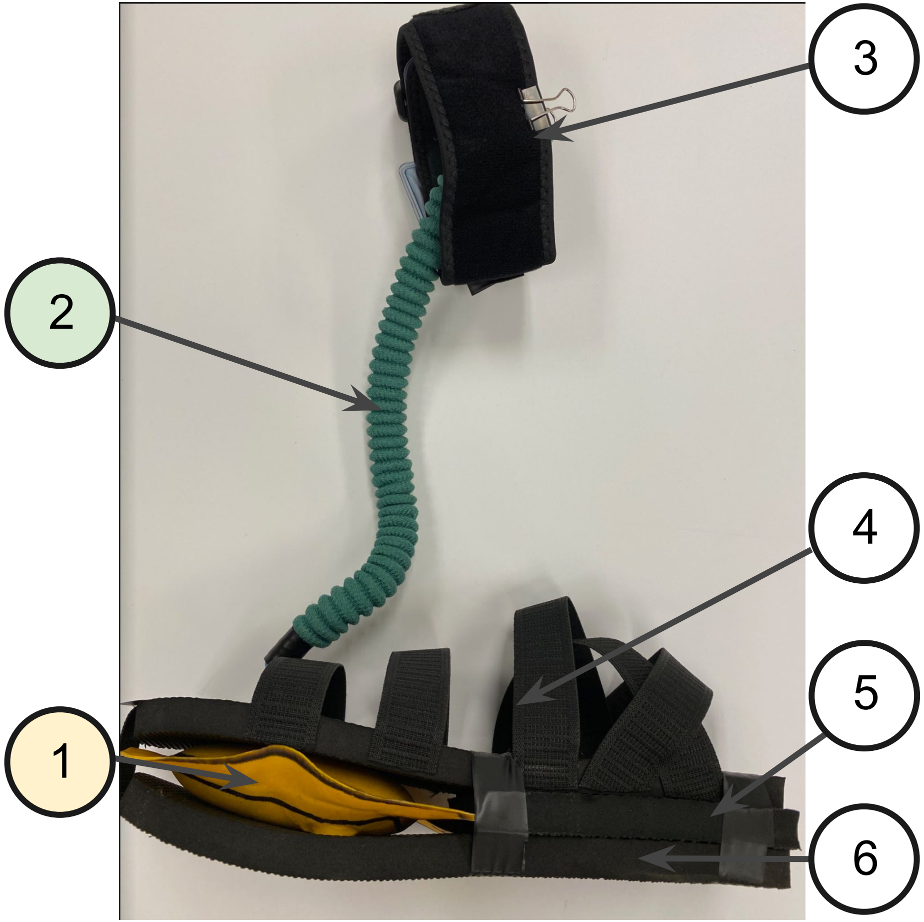
Outline → **Cut** → **Iron** → **Assemble**

1.5 hrs of Manufacturing Time

Methods — Full Assembly



Bill of Materials	
#	**Part Name**
1	Reservoir
2	Actuator
3	Velcro Strap
4	Modified flip flop with elastic straps
5	Wedge spacer
6	Modified flip flop base



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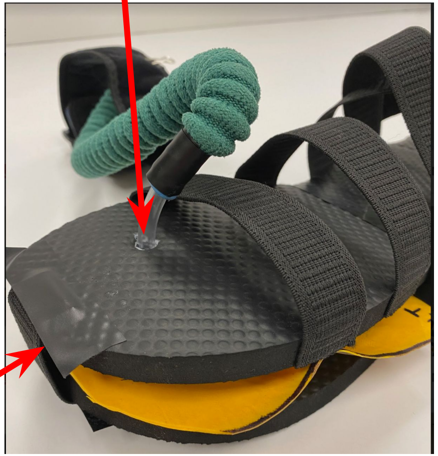
Methods - Features

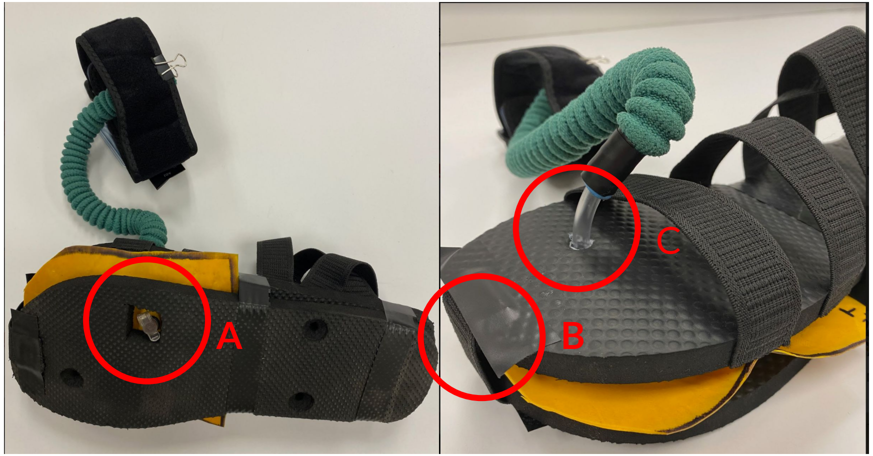
Cut out to fill reservoir with air (flush with flip flop)

Actuator attachment to reservoir mimics flip flop



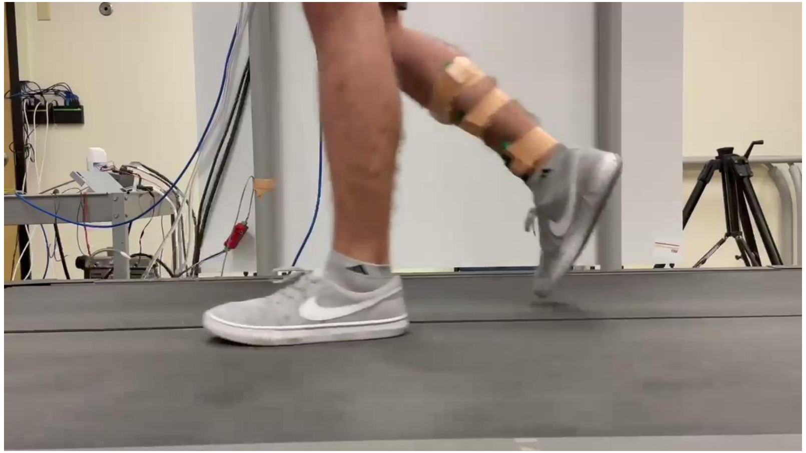
Elastic limit strap (to prevent tripping)

Methods - Features



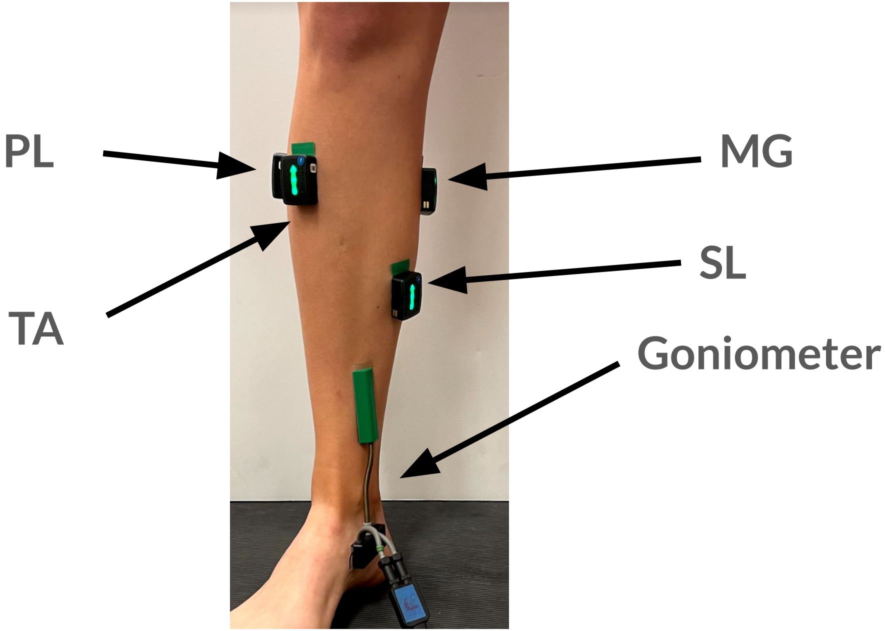
Experimental Design — Preliminary

- Setting up experiment
- Restrictions
- Device is not one size fits all



Methods — Experimental Protocol

- Collected MVC measurements and calibrated goniometer

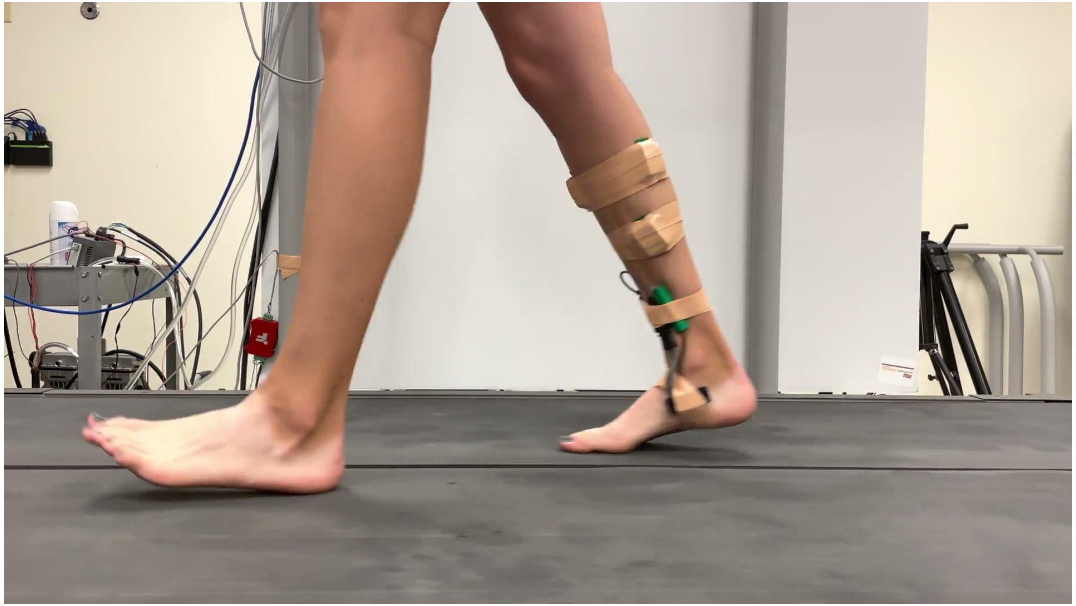


Three Experimental Conditions

(3 min each)

Results — Demo

Baseline *Walking barefoot*



Results — Demo

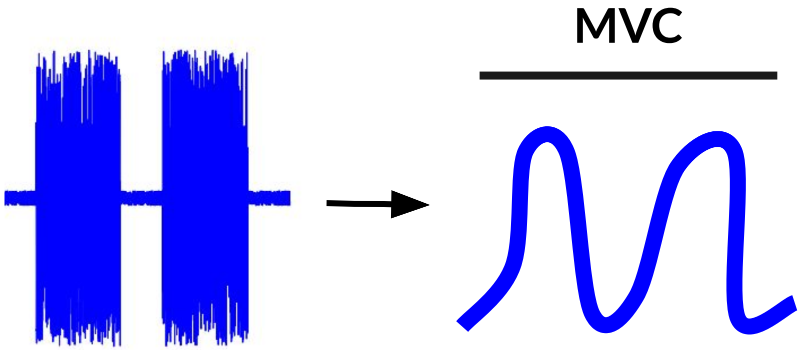
Passive *Actuator disconnected*

Results — Demo

Active *Actuator connected*

Results — Data Processing

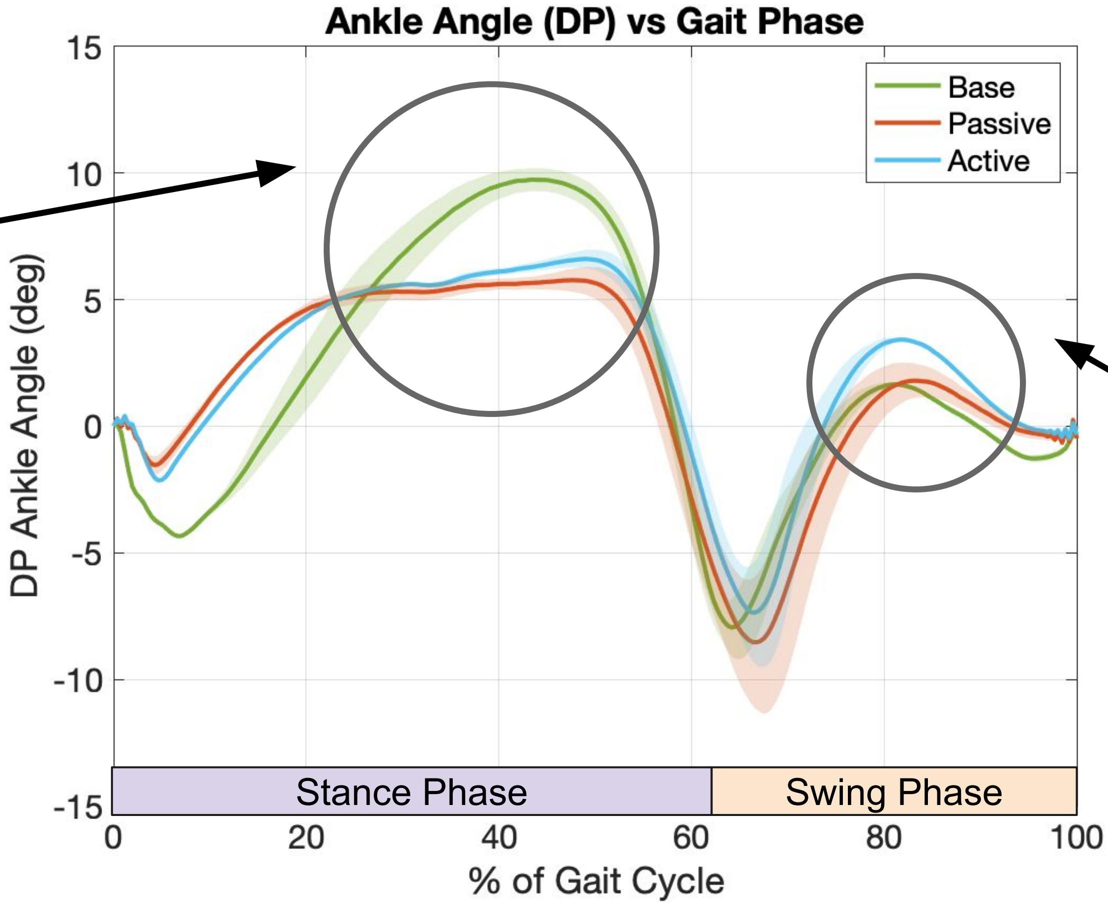
- EMG and goniometer data filtered/scaled using filtering techniques found in previous gait studies [4]
- Analysis code identifies heel strike from force plate data
  - Each step can be overlapped to find mean response



Visualizing EMG Filtering

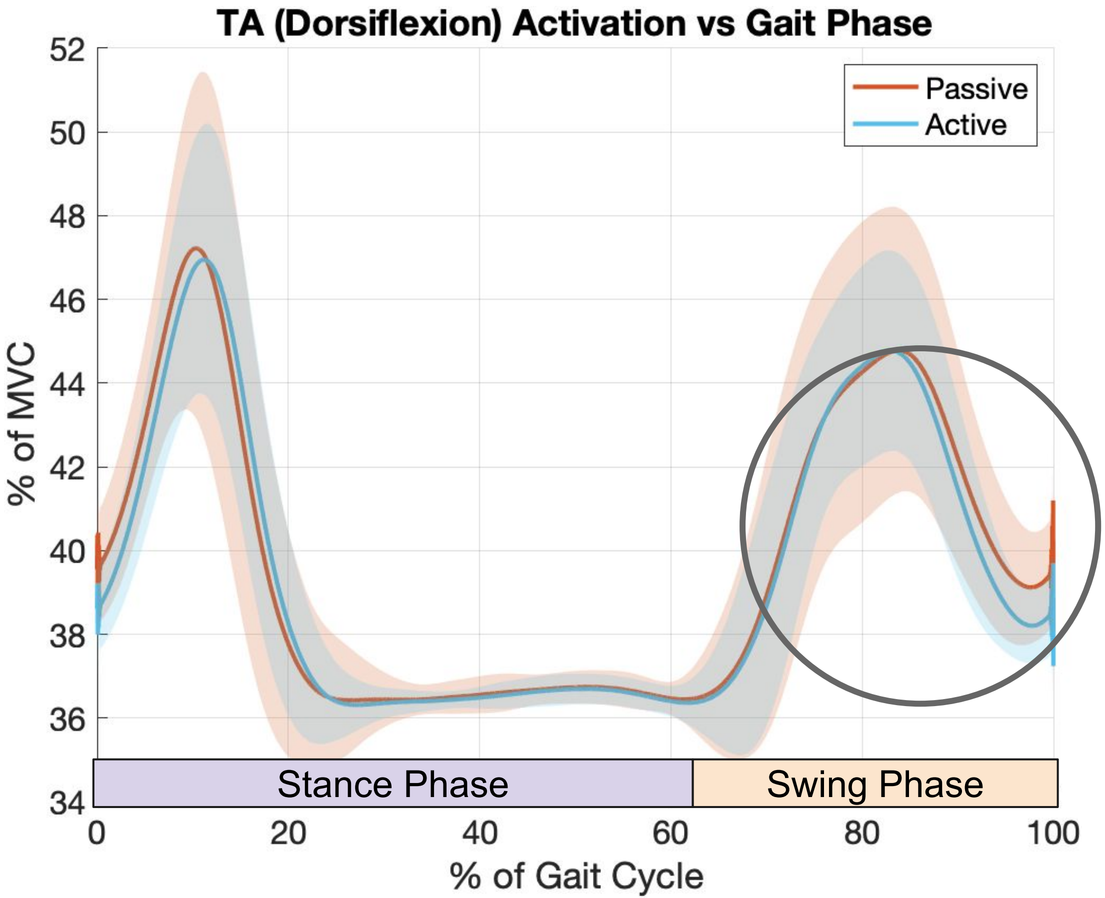
Results — Ankle Angle

Reservoir placement during stance affected gait



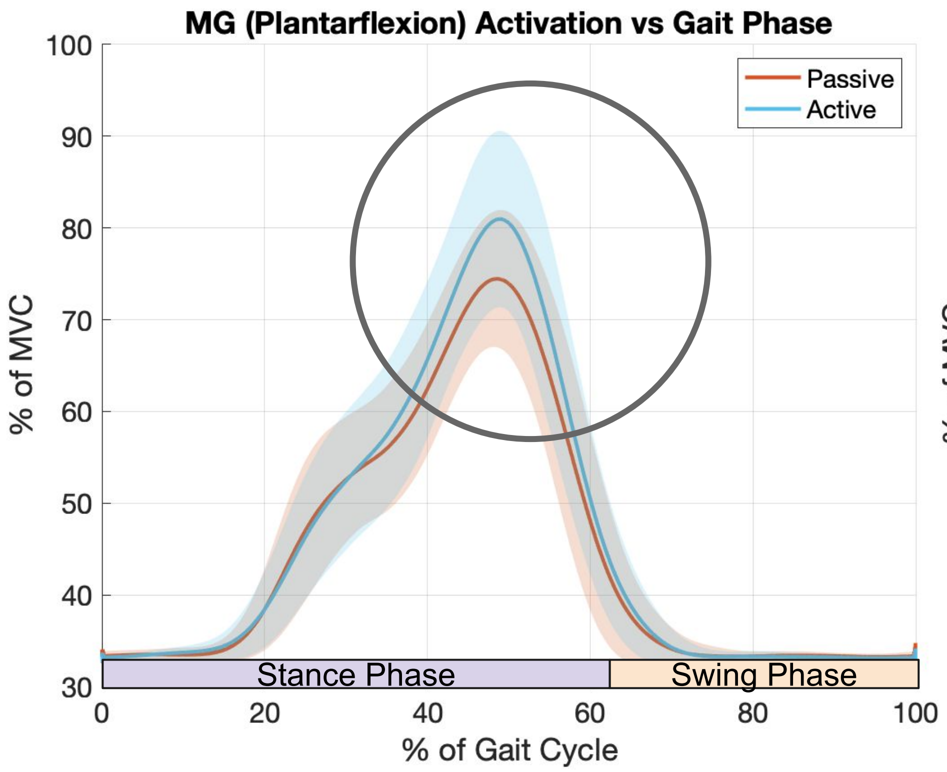
The actuator increased dorsiflexion during swing

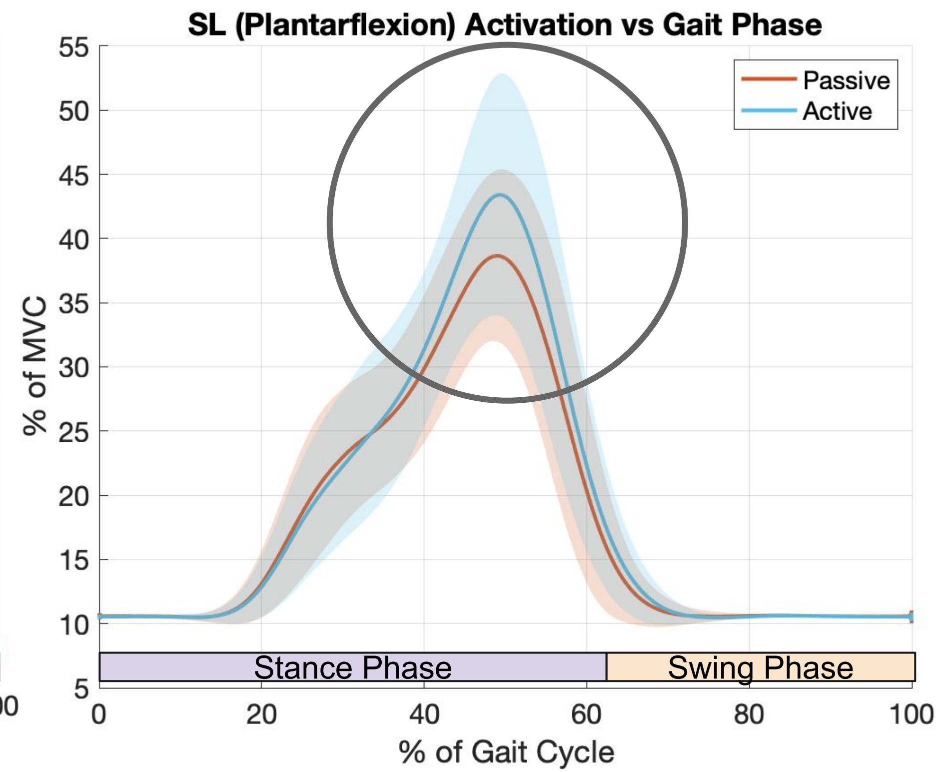
Results — Dorsiflexion Muscle Activation



Some reduction in effort during swing

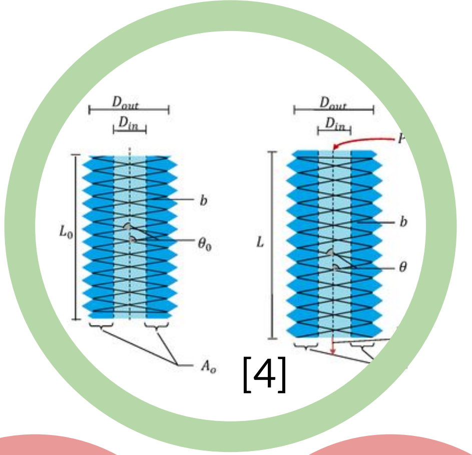
Results — Plantarflexion Muscle Activation





Discussion — Comparing Our Results

- Effect of common AFOs: “several persons tried to plantarflex their ankles during toe-off, although they were restricted in this direction by the AFO” [5]
- We created a low cost **pneumatic artificial muscle** device without subjects carrying air compressors/motors in a **backpack** or **tethered system**



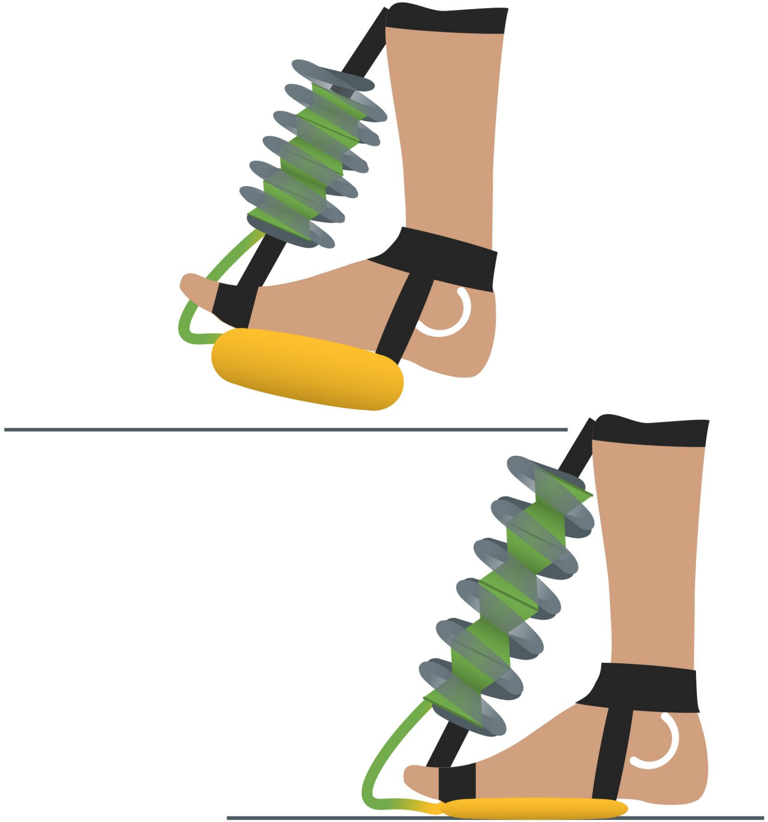
[4]

Future Work

- Improve design
  - Shoe design, reservoir placement
  - Material selection
- Gather data from more subjects
  - This was difficult since we made one sized shoe
- Directly compare to other affordable braces on the market

Conclusion

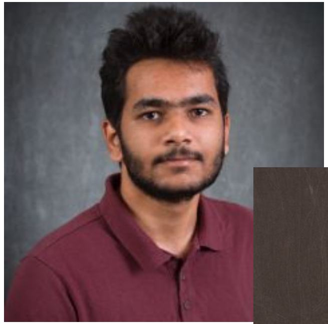
- Viable design to assist dorsiflexion
    - Real-world application
- Create inexpensive and accessible prototype
- This concept could be expanded upon to create untethered, soft wearable robots



Acknowledgments

Thank you to...

- Omik for helping us run the experiments and teaching us how to perform analysis
- Dr. Lee for letting us use the lab equipment
- Dr. Marvi for his guidance on our project



References

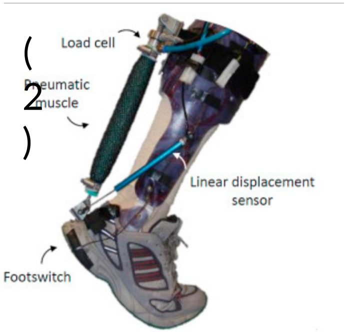
[1] Di Natali C, Sadeghi A, Mondini A, et al. Pneumatic Quasi-Passive Actuation for Soft Assistive Lower Limbs Exoskeleton.
Front Neurorobot. 2020;14:31. Published 2020 Jun 30. doi:10.3389/fnbot.2020.00031
[2] S. Galle, W. Derave, F. Bossuyt, P. Calders, P. Malcolm, D. De Clercq,Exoskeleton plantarflexion assistance for elderly,Gait & Posture,Volume 52,2017,Pages 183-188,ISSN 0966-6362
[3] https://rewalk.com/restore-exo-suit/
[4] Save, O. (2020). Variable Impedance as an Improved Control Scheme for Active Ankle Foot Orthosis. Thesis (M.S.)--Arizona State University, 2020.
[5] Johanna F. Geboers, Maarten R. Drost, Frank Spaans, Harm Kuipers, Henk A. Seelen, Immediate and long-term effects of ankle-foot orthosis on muscle activity during walking: A randomized study of patients with unilateral foot drop, Archives of Physical Medicine and Rehabilitation, Volume 83, Issue 2, 2002, Pages 240-245,
[6] Skorina, E., Luo, M., Oo, W., Tao, W., Chen, F., Youssefian, S., Rahbar, N., & Onal, C. (2018). Reverse pneumatic artificial muscles (rPAMs): Modeling, integration, and control. PloS One, 13(10), e0204637–e0204637. https://doi.org/10.1371/journal.pone.0204637

Questions?

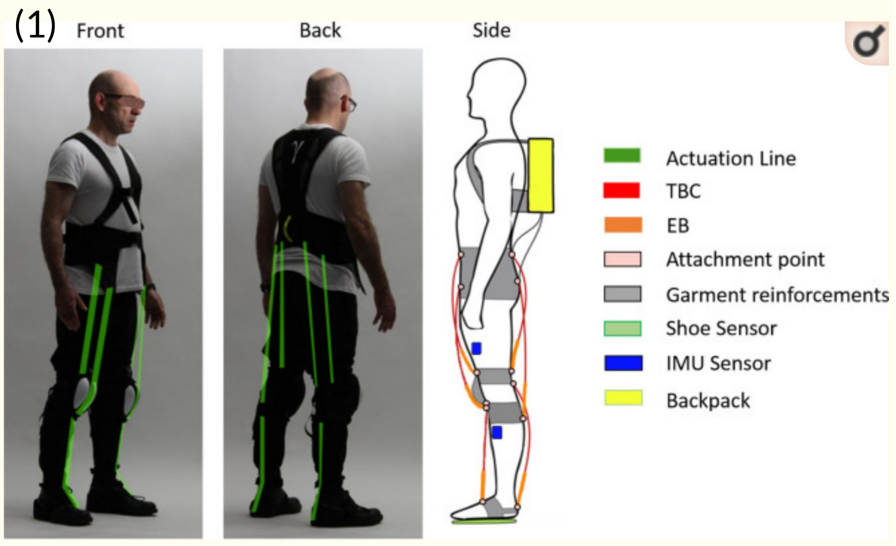
Introduction - State of the Art

- Similar designs
- State of the art devices (quick review)

(2)

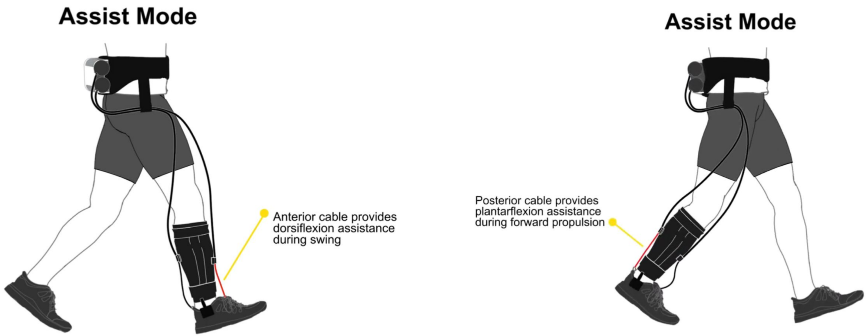


(1)



(2)

ReWalk Robotics:
ReStore Exosuit



Final Presentations:

The final presentations will be online only and will be held on 4/19/21 (12-1:15 pm), 4/21/21 (12-1:15 pm), and 4/28/21 (12:10-2 pm). We will follow the same order of teams that we used for midterm presentations. Each team will have 15 minutes to present the project with additional 5 minutes for questions. A live demo of the final physical prototype/program is highly recommended. If a live demo is not possible (with justified reasons), there should be videos showing the performance of the robot.

The recommended topics to be discussed during the final presentations are as follows:

- **Introduction:**
  - The bio-inspiration process (state the problem and why it is important, model organism, inspirations taken towards design and control of the robot)
  - Quick review of the state of the art
- **Methods:**
  - Discuss the design and fabrication of the prototype/code development
  - Discuss the testing procedure
  - Discuss any modeling performed
- **Results and Discussion:**
  - Show a live demo (or videos of the robot)
  - Present results (experimental/simulations)
  - Discuss the results and compare to the literature, do the results make sense? lessons learned, challenges
- **Conclusions and Future Directions:** Summarize your work and discuss potential future improvements