

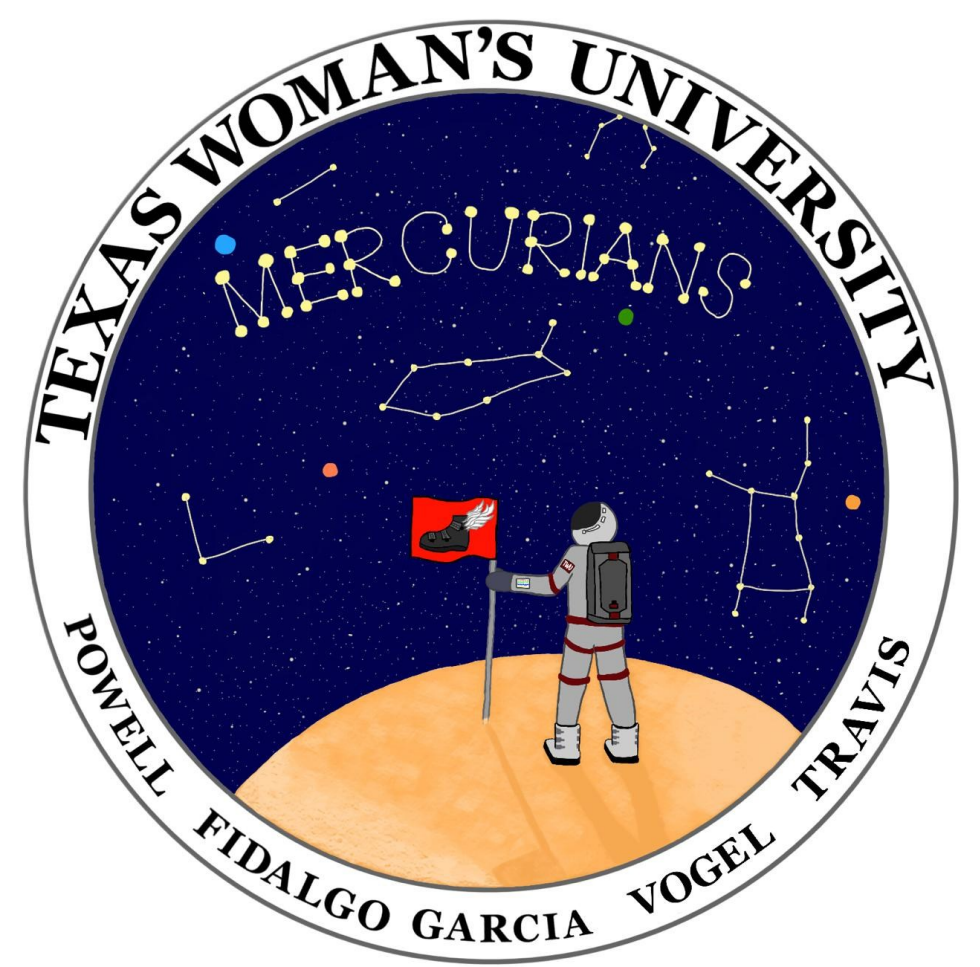
Pneumatic Device for Mitigating Muscle Atrophy in Lower Extremities During Long-Duration Spaceflight

Team Mercurians

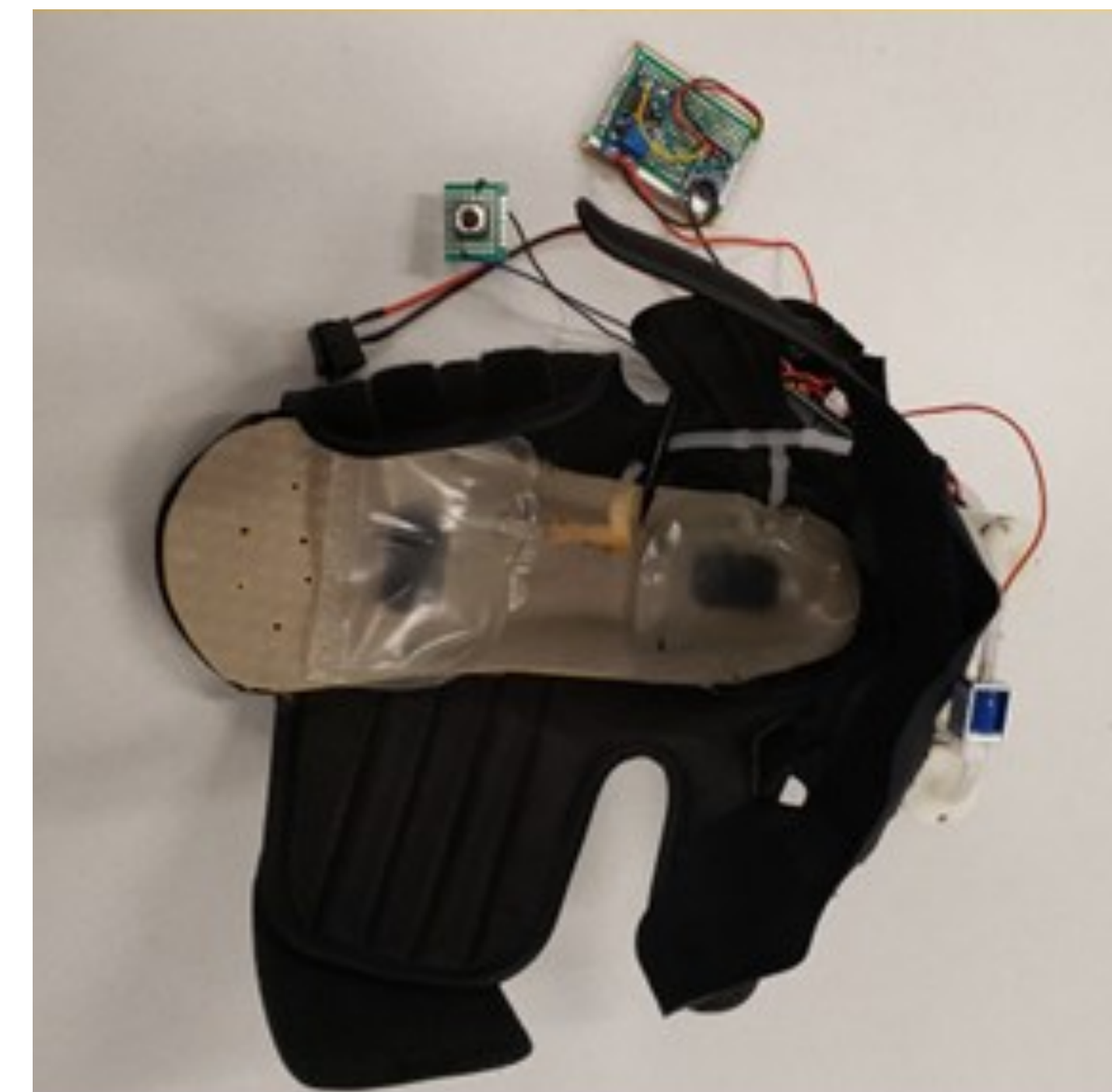
Gabriella Powell (Team Lead), Candela Fidalgo Garcia, Austin Travis, Natalie Vogel

Faculty Mentor: Shaochen Huang, Ph.D.

NASA Mentor: Baraquiel Reyna, Ph.D.



PREVIOUS DESIGN SUMMARY



- ◊ A boot was developed to mitigate soleus muscle atrophy.
- ◊ Forefoot and calcaneus airbags alternated inflation to mimic gait.
- ◊ Mechanoreceptor stimulation activated the soleus, reducing atrophy.

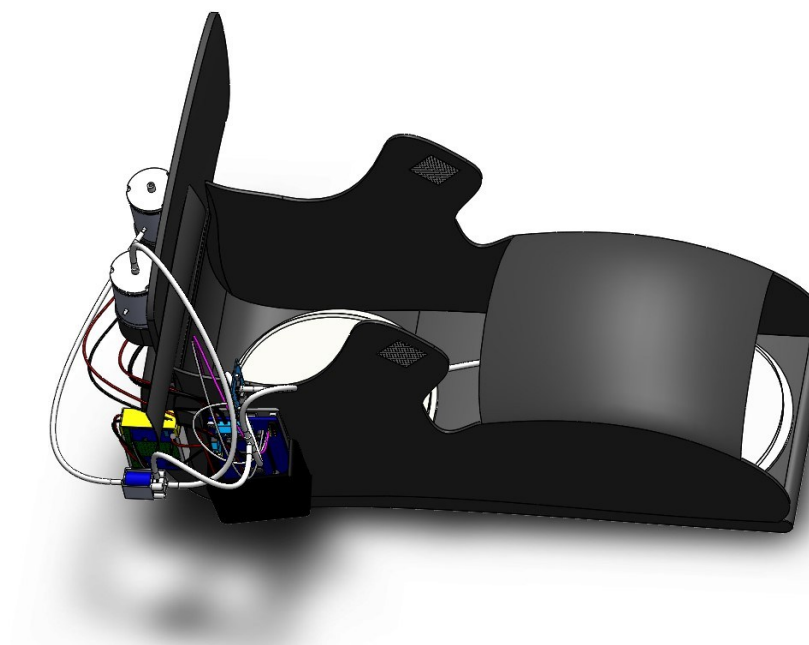


Figure 1: Previous Boot

Figure 2: Previous Boot Model

BACKGROUND

Long-Duration Spaceflight on Muscle Health



In microgravity, body weight is removed, resulting in unloading of postural muscles and reduced neuromuscular activation. Lower limb muscles are significantly affected because they sustain body weight against gravity. A reduction in muscle mass can affect an astronaut's ability to perform tasks and increase the risk of injury.^{2,5}

Consequences



Countermeasure

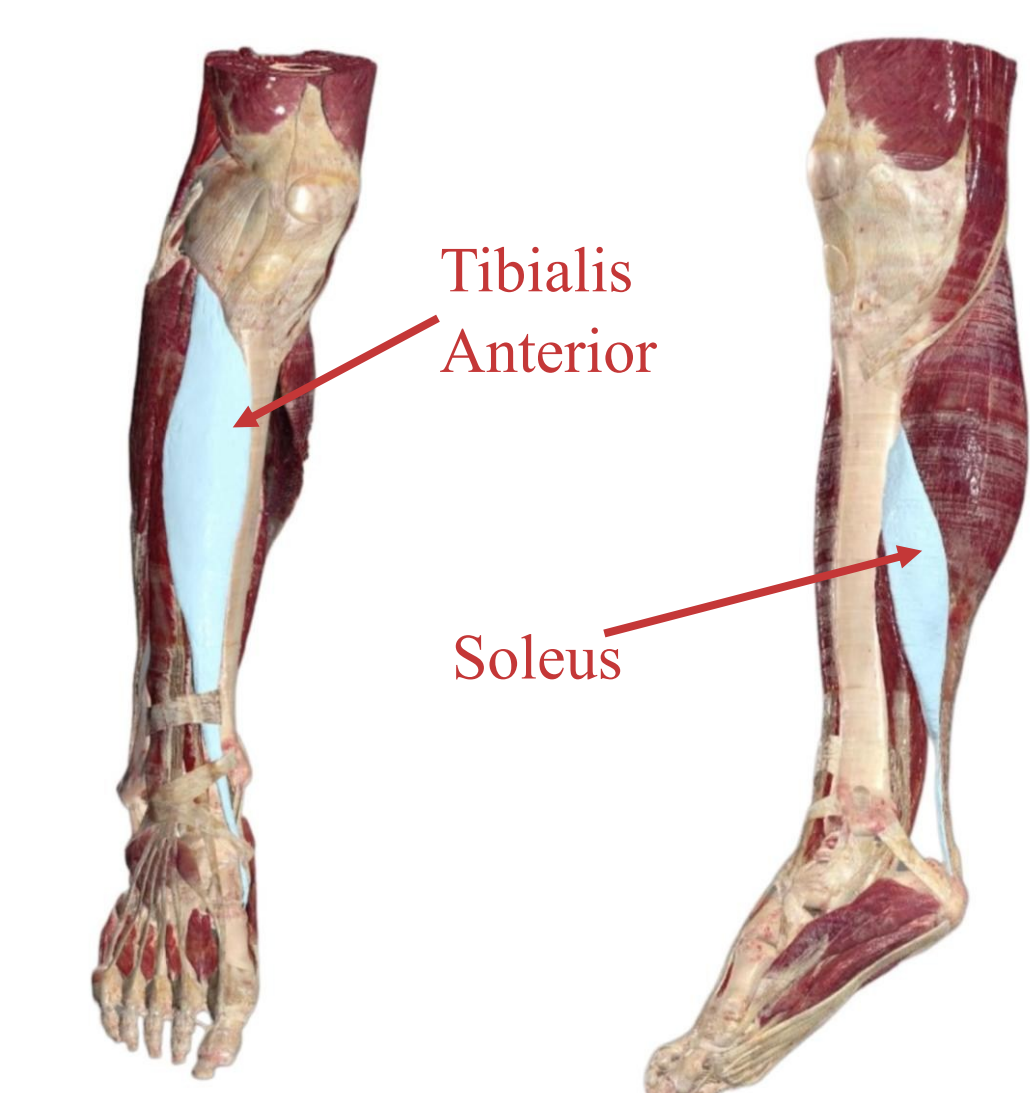


Figure 3: Tibialis Anterior (Left) & Soleus (Right)

Our device utilizes mechanical stimulation via integrated pneumatic pistons that use air to deliver high pressure to the heel and the forefoot in 0.2 seconds to mimic gait patterns.^{3,5}

Activation of the soleus and tibialis anterior muscles via mechanoreceptor stimulation may lead to maintenance of lower limb skeletal muscle stiffness and tone. This would ultimately mitigate neuromuscular declines.^{1,4,7,8,12,13}

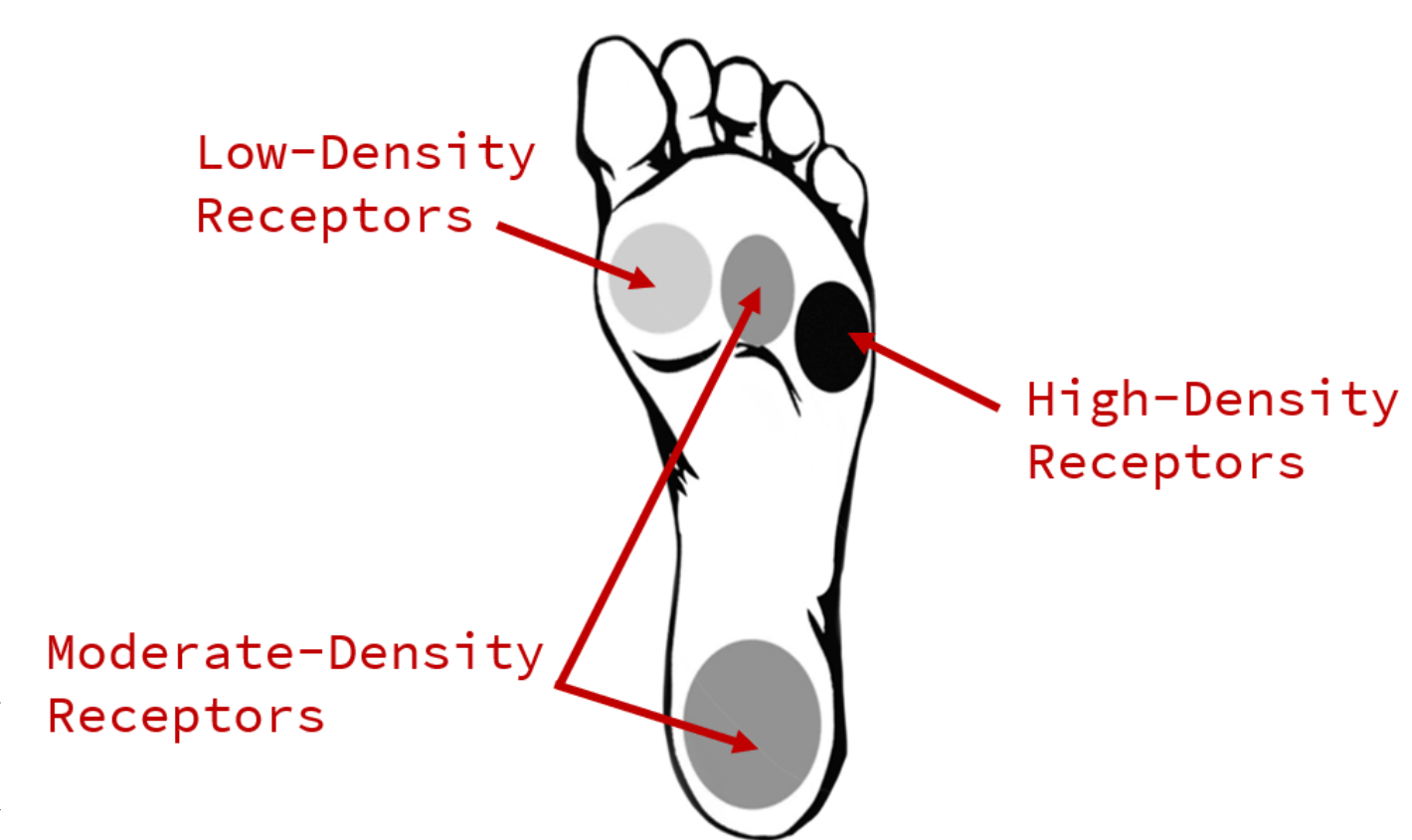


Figure 4: Foot Mechanoreceptors

PROJECT OBJECTIVE

In order to mitigate lower-limb muscle atrophy that results from reduced loading in microgravity, a device that stimulates foot mechanoreceptors passively, via pneumatic pressure to enhance neuromuscular activation was created.

DESIGN

Highlighted Components

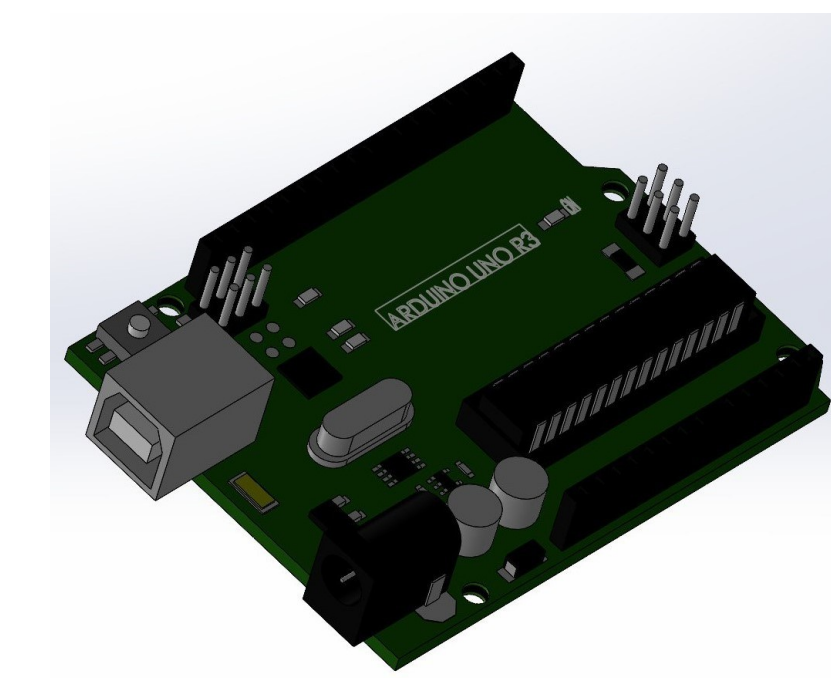


Figure 5: UNO Board
1.3 oz

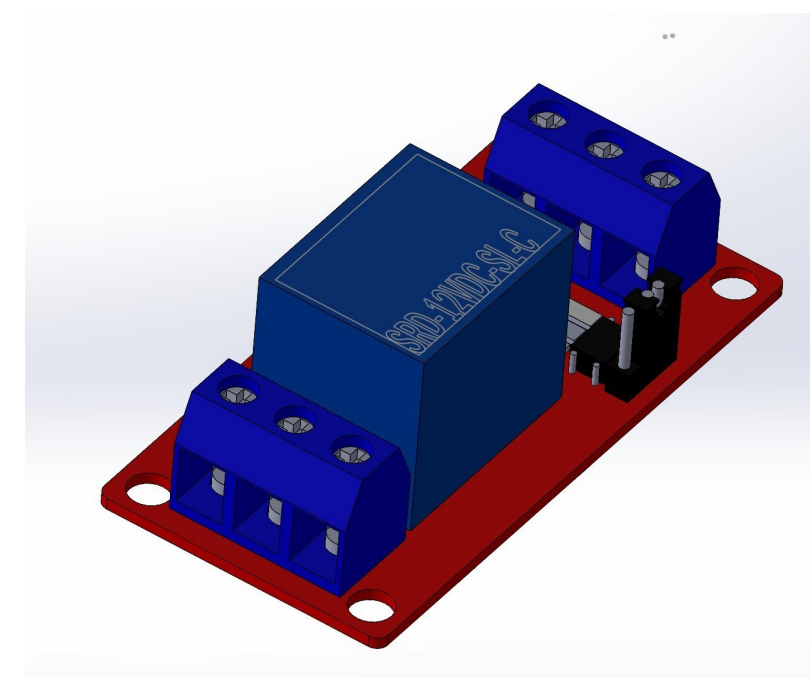


Figure 6: Relay Board
1.2 oz ~ 12V

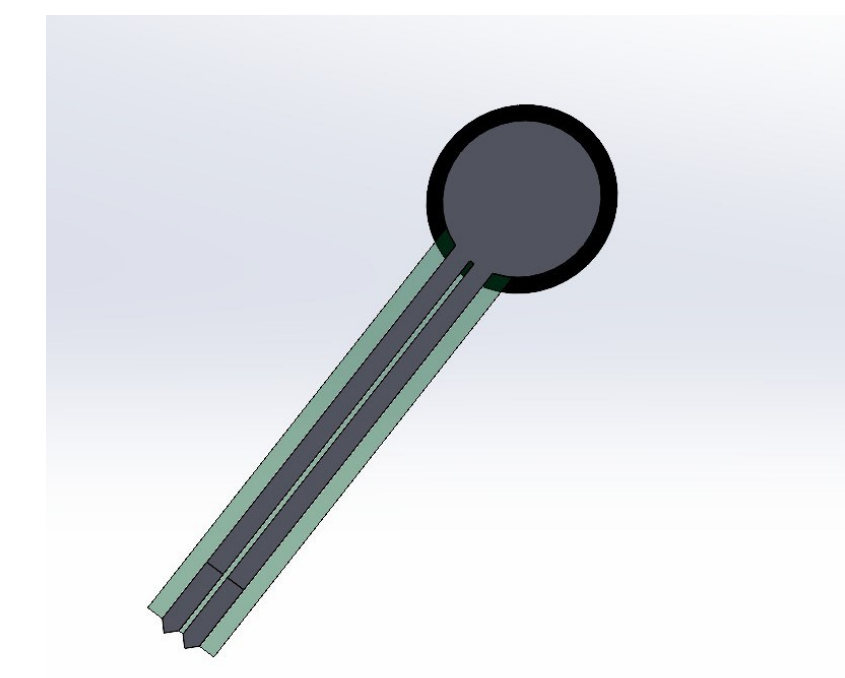


Figure 7: Force Sensor
60.4mm x 18.33mm ~ 0.3N-10N

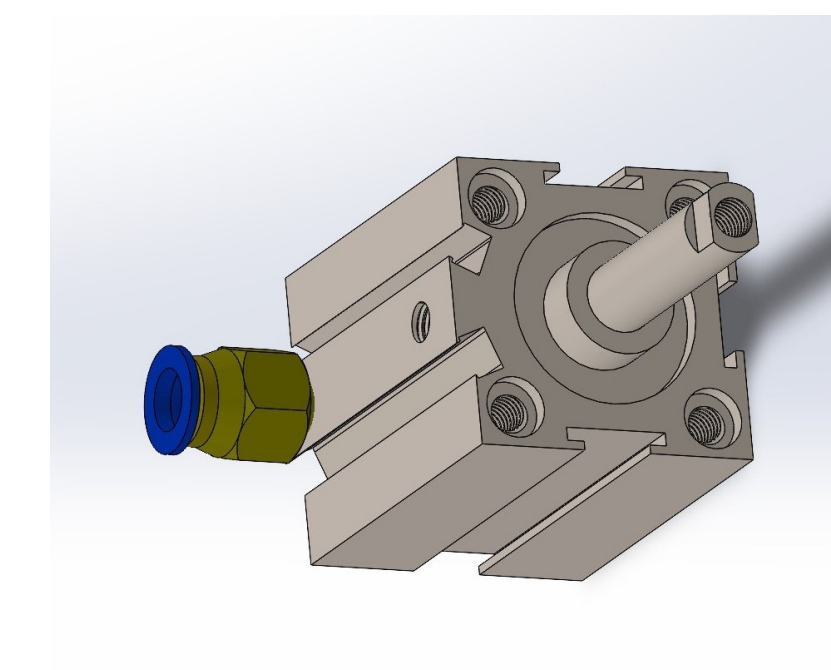


Figure 8: Pneumatic Piston
3.5 oz

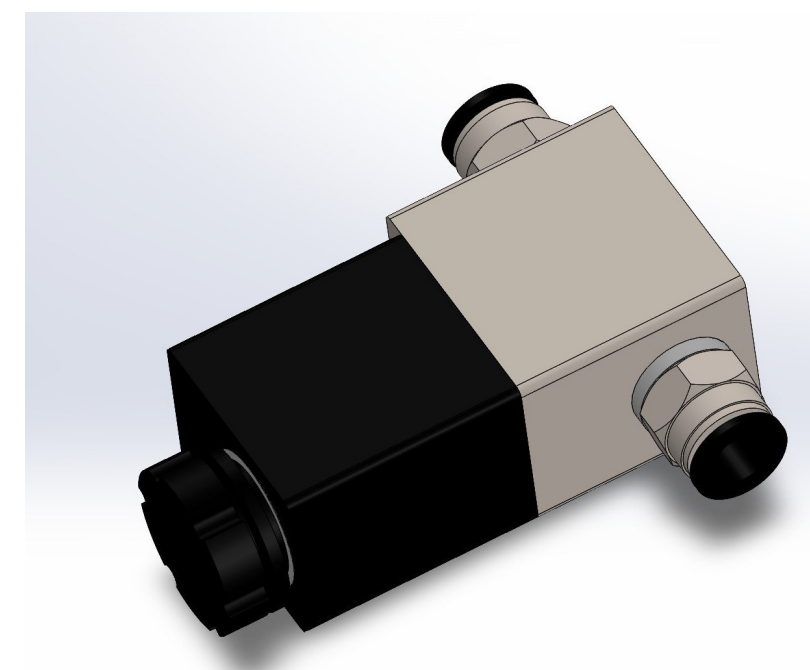


Figure 9: Solenoid Valve
4.7 oz ~ 12V

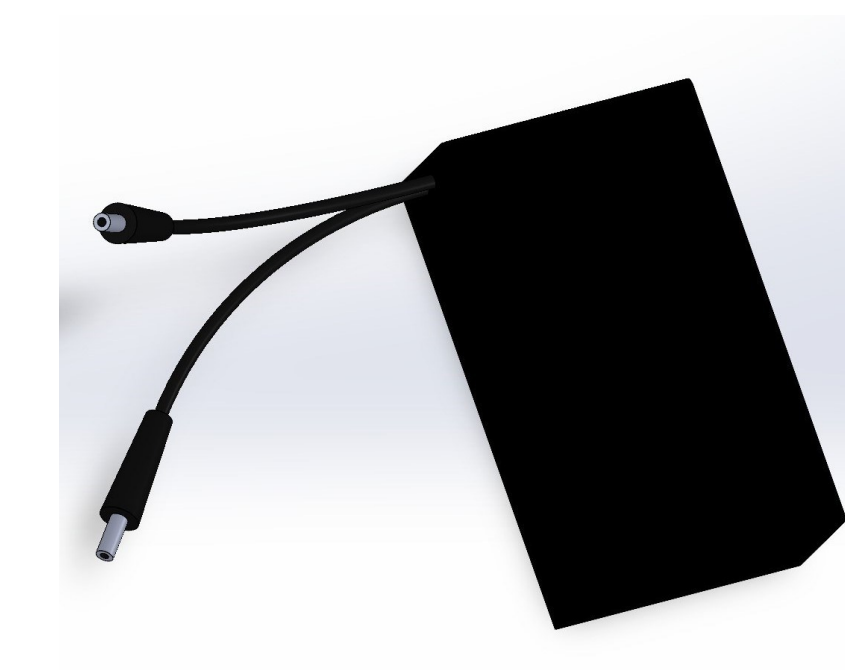


Figure 10: Battery
1.03 oz ~ 12V

Assembled Boot

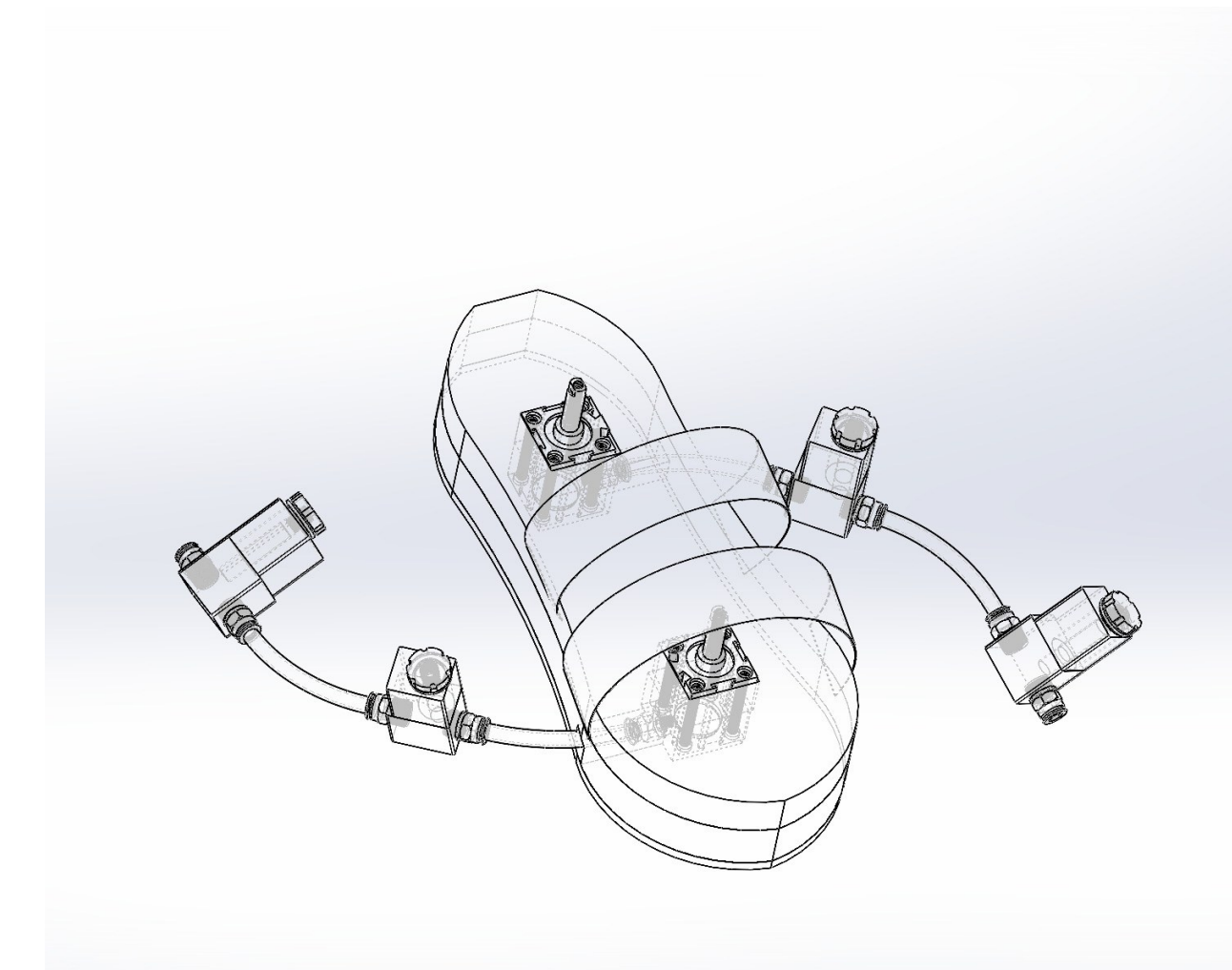


Figure 11: THE BOOT Model [Outline]

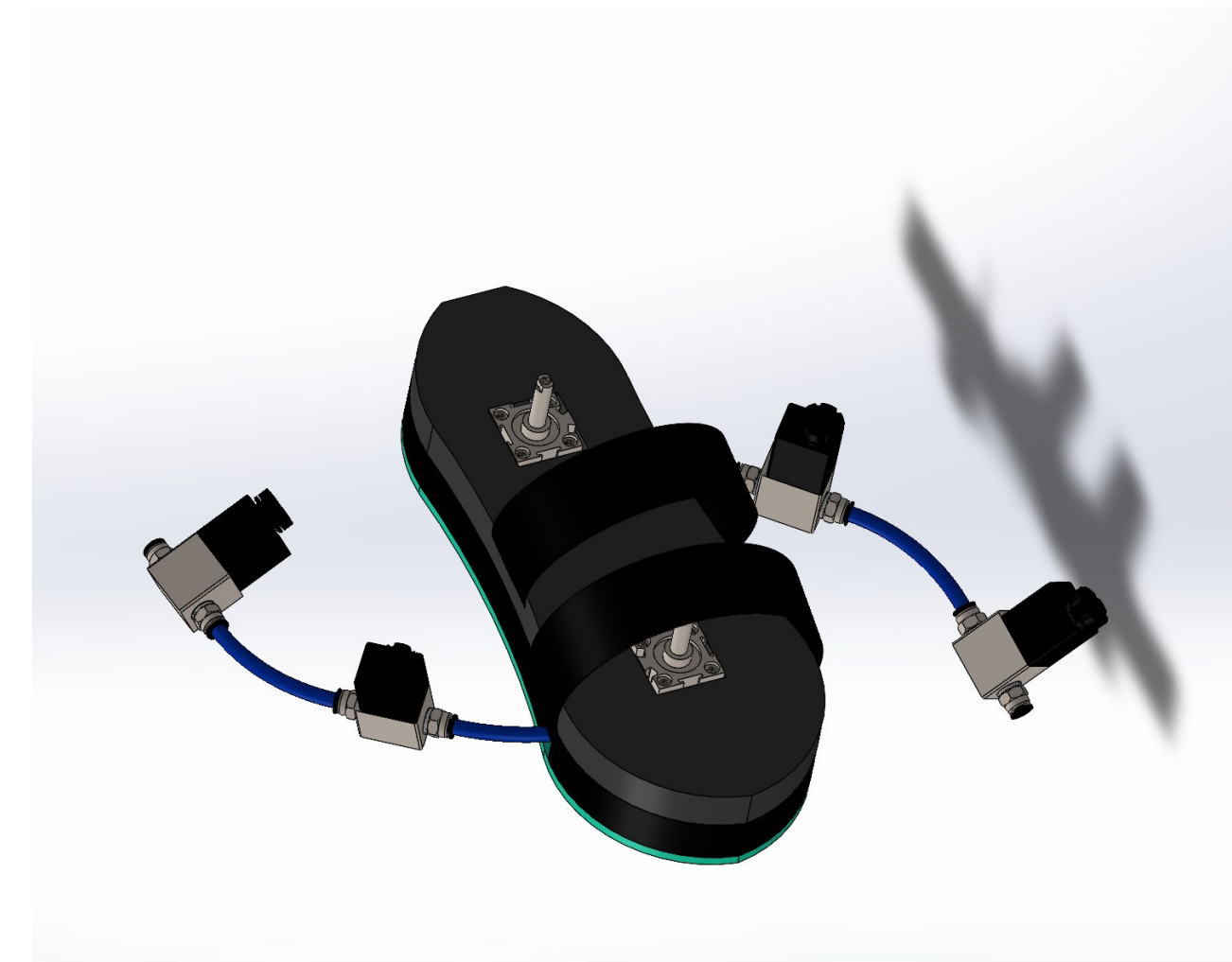


Figure 12: THE BOOT Model [Detailed]

THE BOOT

Therapeutic Exosystem for Biomechanical Oscillation and Overcoming Tissue atrophy

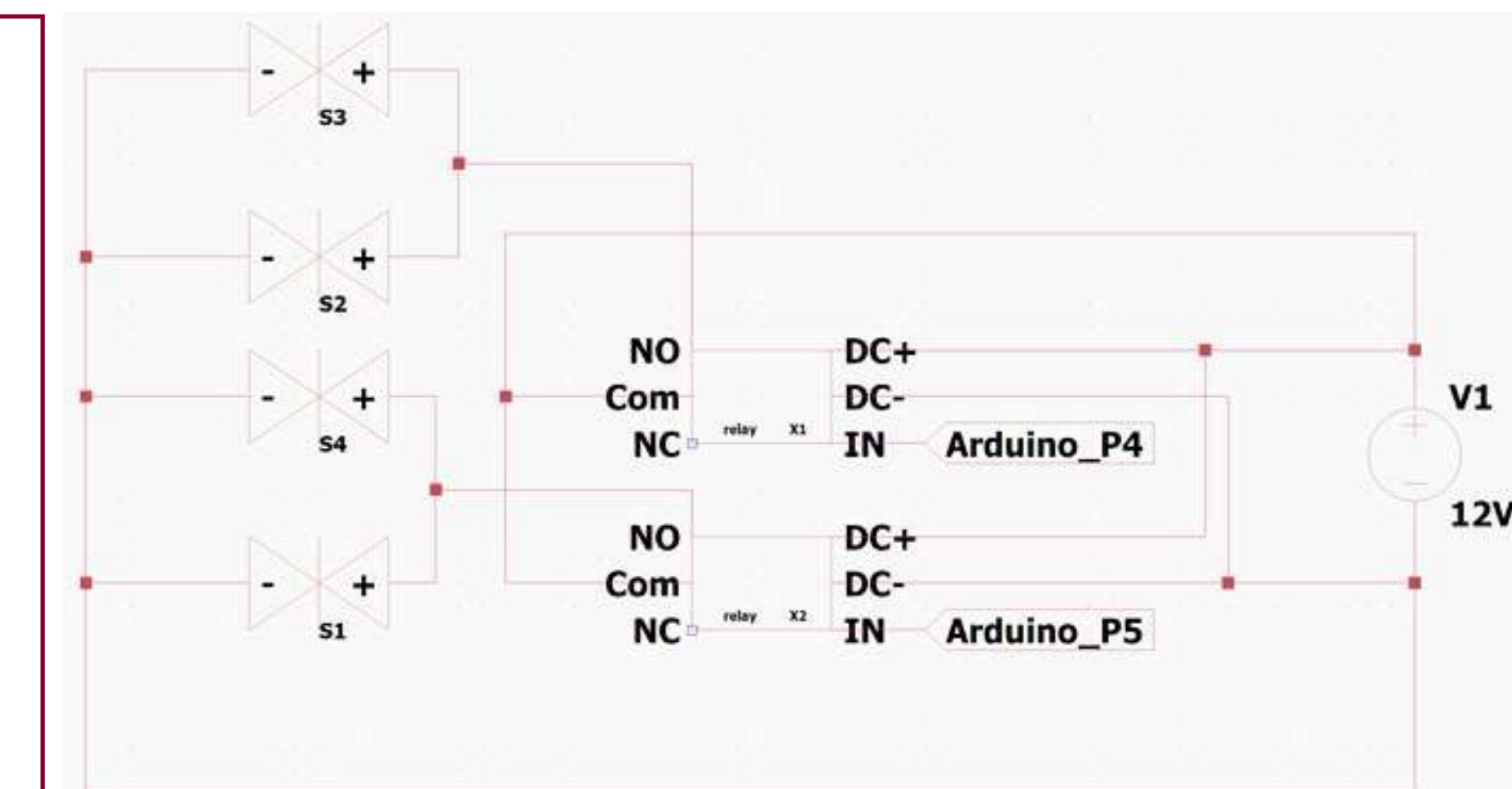


Figure 13: Circuit Layout

PROGRAMMING

Force Sensor Conversions:

Voltage Divider Formula

Readings from FSR in mV

Resistance in Ω

Conductance in $\mu\Omega$

Force in Newtons

Pressure in kPa

```

// ----- SETUP -----
// (force > forceIn)
// (forceIn > force)
// (force > forceIn)
// (forceIn > force)
// ----- FSR READINGS -----
// (forceIn > forceIn)
// (force > force)
// (forceIn > forceIn)
// (force > force)
// ----- FSR READINGS -----
// (forceIn > forceIn)
// (force > force)
// (forceIn > forceIn)
// (force > force)

```

Figure 14: Code Sample

TESTING PROTOCOL

Surface Electromyography (EMG)

EMG measures muscle electrical activity. Collected in sitting and supine positions. SENIAM electrode placement:

- ◊ Tibialis Anterior: 1/3 [fibular head → medial malleolus]
- ◊ Soleus: 2/3 [medial femoral condyle → medial malleolus]



Figure 15: Sitting EMG



Figure 16: Supine EMG

Force Output

A force output test was conducted in conjunction with the EMG using a force sensor to collect data.

TESTING RESULTS: FORCE

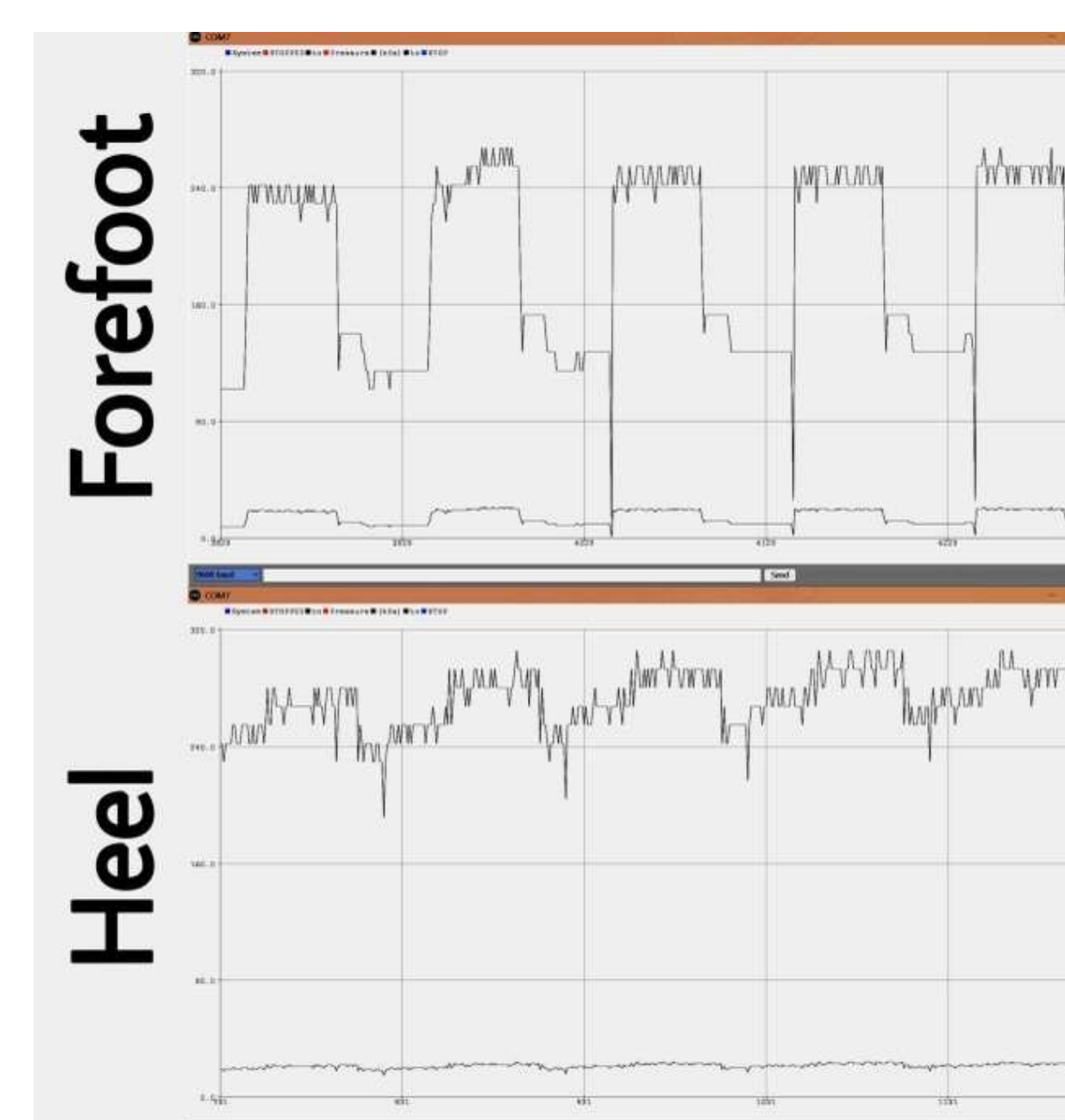


Figure 17: Force Graphs

Force measurements, as displayed on the graphs in figure 17, show clear patterns of force acting on the foot.

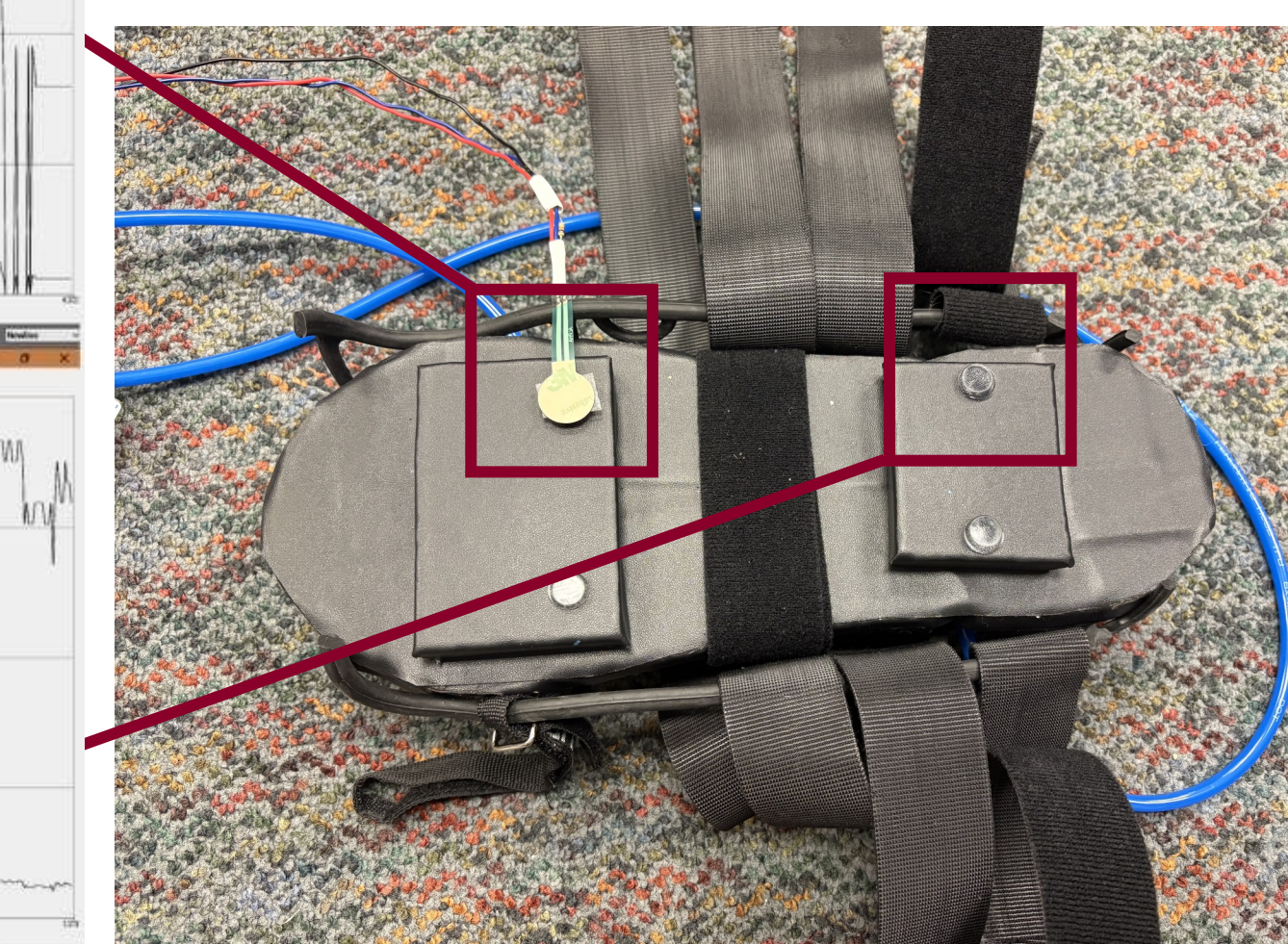


Figure 18: Force Sensor Placement

TESTING RESULTS: EMG

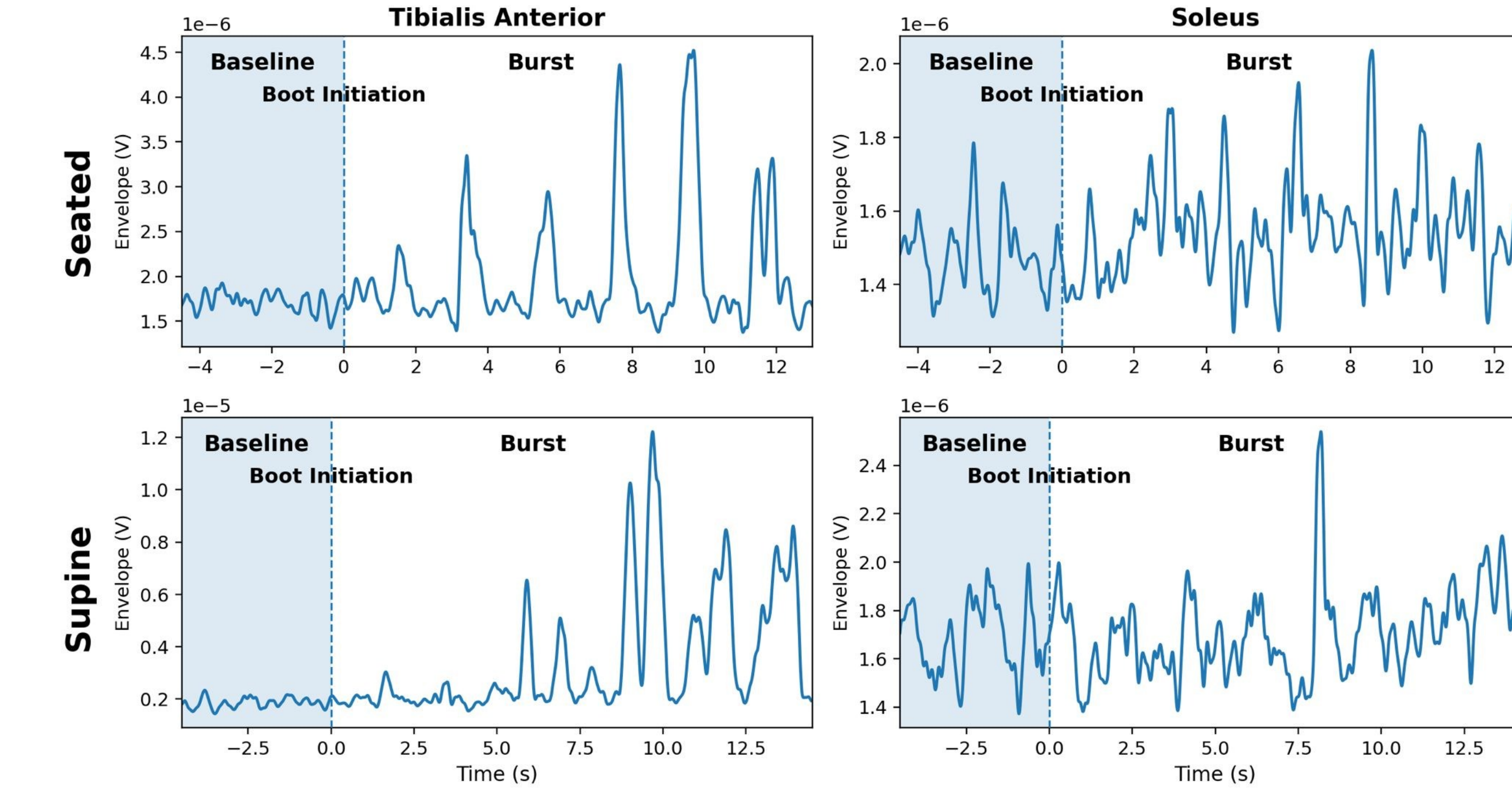


Figure 19: EMG Graphs

EMG testing showed strong activation of the tibialis anterior. Soleus activation was less significant due to crosstalk and potential artifacts, indicating a need for further testing.



Figure 20: Active EMG

TABLE OF IMPROVEMENTS

Aspect	Improvement	Impact
Pressure/Force	Increased input pressure and output force	Device performance ↑
Muscle Selection	Included tibialis anterior with soleus	Muscle targeting ↑
Mechanism	Replaced airbags with pneumatic mechanical system	Reliability and control ↑

Figure 21: Improvements from Previous Design

FUTURE DIRECTIONS

- ◊ Reduce weight for portability
- ◊ Long-term testing and further soleus evaluation
- ◊ Improve ground reaction force systems for microgravity
- ◊ Integrate current NASA systems for power efficiency

CONCLUSION

THE BOOT passively stimulates foot mechanoreceptors via pneumatic pressure and was proven to successfully activate lower-limb musculature for the mitigation of muscle atrophy.

ACKNOWLEDGMENTS

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QUESTIONS

All questions can be sent to the team lead Gabriella Powell at gpowell14@twu.edu.

References can be found by scanning the QR code.

