Mitigation of Muscle Atrophy During Long-Duration Spaceflight

Team Pleiades

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FALL 2024 RECAP

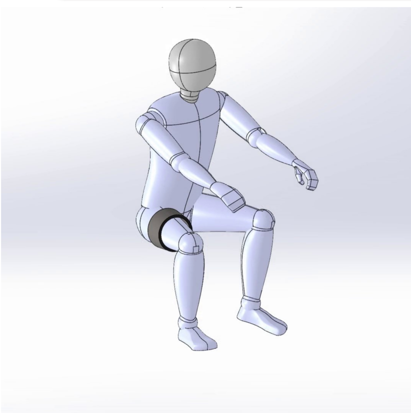


Figure 1: HALO placement

This past fall, Team Pleiades developed the HALO (Hypertrophic Aide for Limb Occlusion) to mitigate muscle atrophy in spaceflight.

The cuff-like device, which occluded blood flow to the leg, applied pressure to the femoral artery.

The HALO was effective in providing a physiological stimulus to elicit muscle growth.

BACKGROUND

Long-duration spaceflight on muscle health

↑ MUSCLE DISUSE = ↓ SKELETAL MUSCLE MASS = ↑ MUSCLE ATROPHY

Weight-bearing skeletal muscles are especially susceptible to atrophy due to their larger size.

There is a decrease of 20% in the size of these muscles in the first 5-11 days of spaceflight.

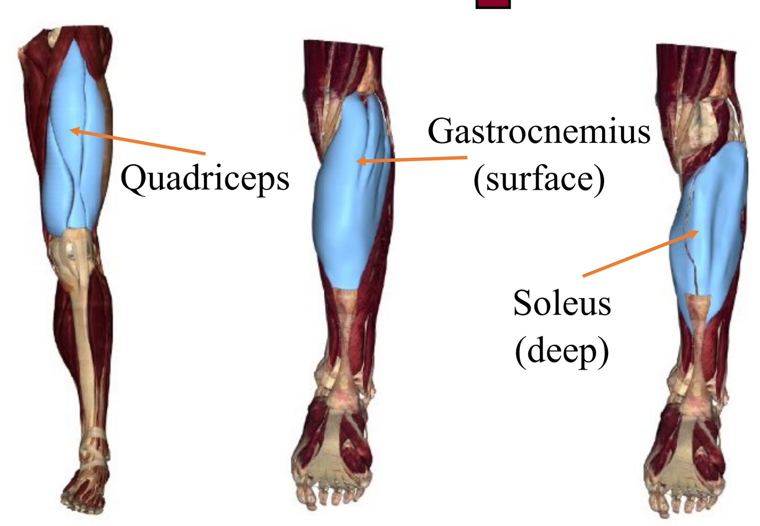


Figure 2: Lower leg musculature

Consequences

↓ MUSCLE STRENGTH = ↓ MISSION TASK PERFORMANCE = ↑ INJURY RISK

Blood Flow Restriction (BFR)

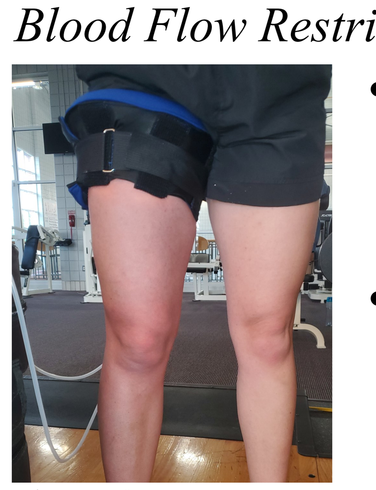


Figure 3: BFR

- Occludes blood flow to a limb by applying pressure to blood vessels
- Low-intensity exercise is utilized while mimicking the physiology of high-intensity exercise

Neuromuscular Electrical Stimulation (NMES)

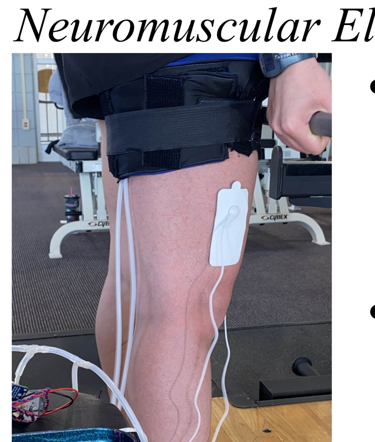


Figure 4: NMES

- Multiple electrical currents are delivered via surface electrodes on muscles
- Elicits fast-twitch fiber recruitment, circulation, and re-innervation, leading to improved muscular health


Figure 5: BFR+NMES

PROJECT OBJECTIVE

To address lower limb atrophy during spaceflight, we designed a compact device that allows for blood flow restriction and neuromuscular electrical stimulation to be implemented during resistance training to promote muscle hypertrophy and aid in muscle recovery.

TABLE OF IMPROVEMENTS

Addition of Electrical Stimulation	Enhanced benefits and recovery of BFR
Cuff	Improved construction and materials
Airbladder	Created with PVC, pressed with iron
Code	Updated BFR code to maintain pressure
Holder	Updated to be customizable and mobile
Expanded Testing	Inclusion of torque output

Figure 6: Table of Improvements from Fall 2024 to Spring 2025

DESIGN

The device includes components to provide BFR and NMES. The cuff and airbag were customized this semester to enhance performance.

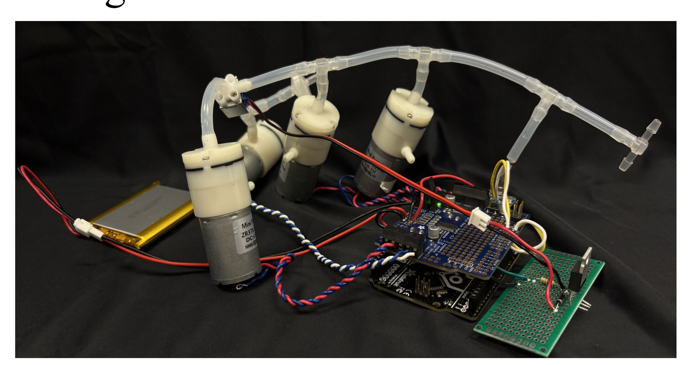


Figure 7: BFR setup

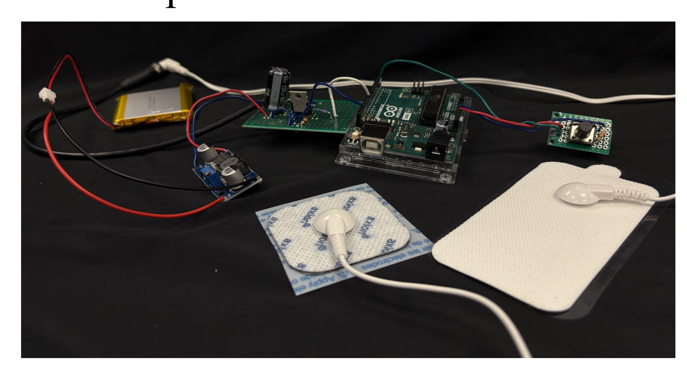


Figure 8: NMES setup

BFR Components	NMES Components
Metro 328 + Motor Shield control 4 DC motors & MPRLS pressure sensor	Arduino Uno controls MOSFET signaling
Inflate air bladder and auto-regulate pressure	3.7V LiPo amplified via XL6009 booster powers muscle electrodes

Figure 9: BFR and NMES components


Figure 10: Cuff

The cuff is a nylon fabric layer with two layers of silver ion fabric. Additional components include a Velcro strap, metal buckle, polyester thread, and flexible plastic internal stiffeners.

PLEIADES

Pressurized
Limb-occlusion with
Electrical-stimulation
Integration for
Attenuating the
Deleterious
Effects of
Spaceflight


Figure 11: PLEIADES device

PROGRAMMING

Blood Flow Restriction (BFR)

To code the PLEIADES, C++ and Arduino IDE software were used. The cuff is inflated to a target range of 100-105 mmHg (Figure 12).

```
const int TARGET_PRESSURE_MIN = 100;
const int TARGET_PRESSURE_MAX = 105;
```

Figure 12: Code for minimum and maximum pressure

The motors run until the cuff reaches the target pressure. If the pressure falls, the motors turn back on. If the pressure rises, the motors shut off (Figure 13).

```
if (inflating) {
  if (gaugePressure < TARGET_PRESSURE_MIN) {
    Serial.println("Inflating...");
    inflate();
    inflating = true;
    holding = false;
  }
  else if (gaugePressure >= TARGET_PRESSURE_MIN && gaugePressure <= TARGET_PRESSURE_MAX) {
    Serial.println("Holding...");
    stopMotors();
    inflating = false;
    holding = true;
  }
  else if (gaugePressure > TARGET_PRESSURE_MAX) {
    Serial.println("Overpressure detected!");
    digitalWrite(VALVE_PIN, HIGH);
    inflating = false;
    holding = false;
```

Figure 13: Automatic inflation logic driven by pressure thresholds

Neuromuscular Electrical Stimulation (NMES)

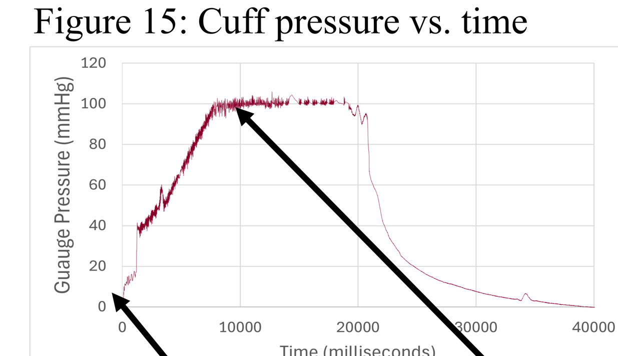
The Uno is programmed to send currents lasting 350 µs at 45 Hz. These pulses are delivered for 1 sec, followed by a 2-sec rest. The target muscles are stimulated during the concentric phase, while rest occurs during the eccentric and isometric phases (Figure 14).

```
const int NMES_PIN = 9;
const int BUTTON_PIN = 2;
const int FREQ = 45;
const int PULSE_WIDTH = 350;
const int PERIOD = 1000000 / FREQ;
const int STIM_ON = 1000;
const int STIM_OFF = 2000;
```

Figure 14: NMES code

TESTING RESULTS: OPERATION

Figure 15: Cuff pressure vs. time

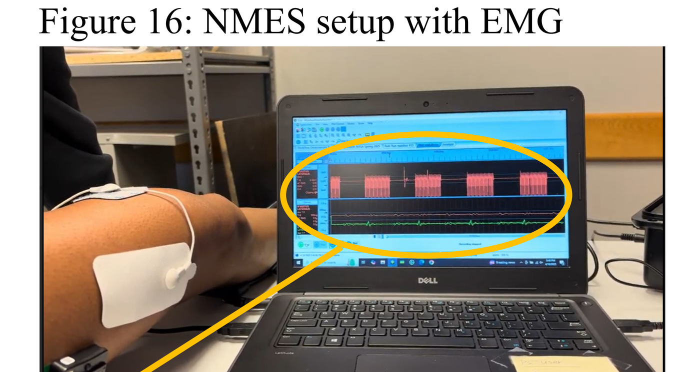


When deflated, the pressure of the air bladder reads 0 mmHg

When inflated, the pressure is approximately 100-105 mmHg

The current was verified using surface electromyography (EMG)

Figure 16: NMES setup with EMG



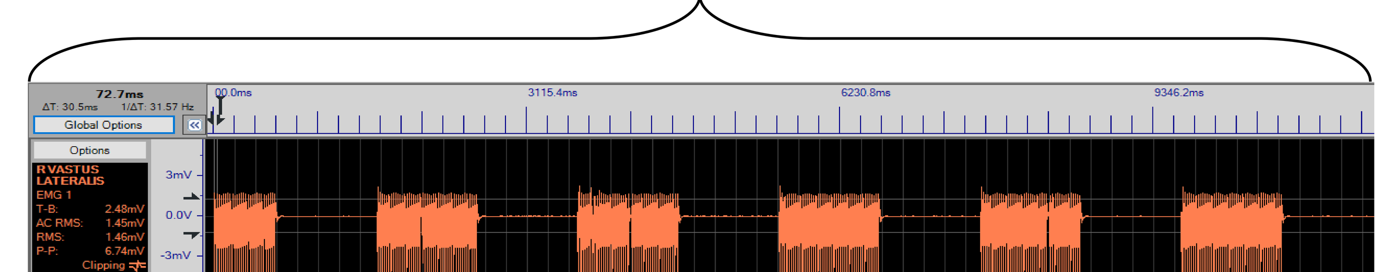
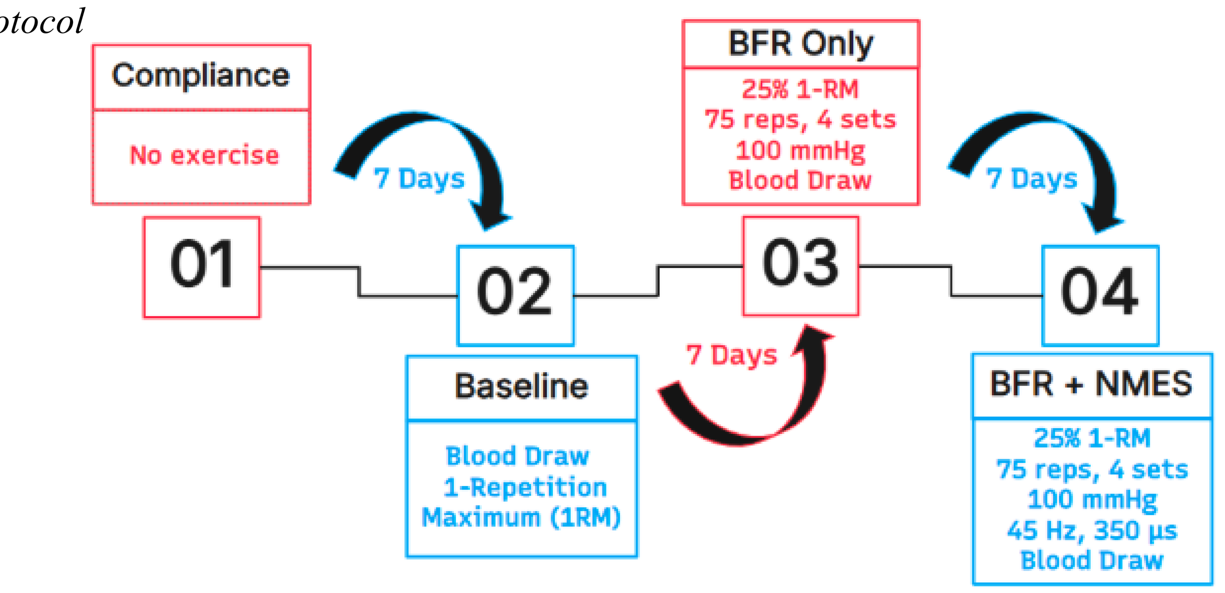


Figure 17: EMG reading during NMES stimulation with an on-off cycle

TESTING RESULTS: EXERCISE

Protocol



EXERCISES

Romanian Deadlift, Back Squat, Deadlift, Single-leg Heel Raise, Single-leg Knee Extension

Vascular Endothelial Growth Factor

↑ ANGIOGENESIS and ↑ CIRCULATION and ↓ ARTERIAL STIFFNESS

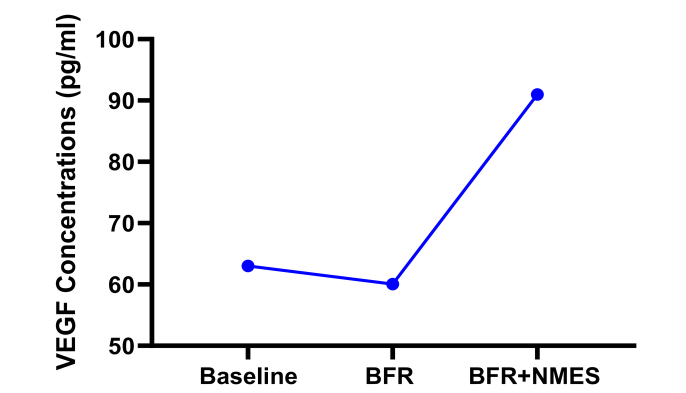
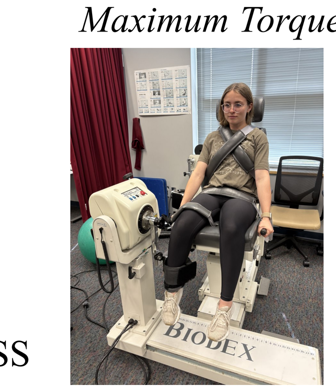


Figure 18: VEGF concentrations

Maximum Torque Output



↑ PERFORMANCE and ↑ STRENGTH and ↓ INJURY RISK

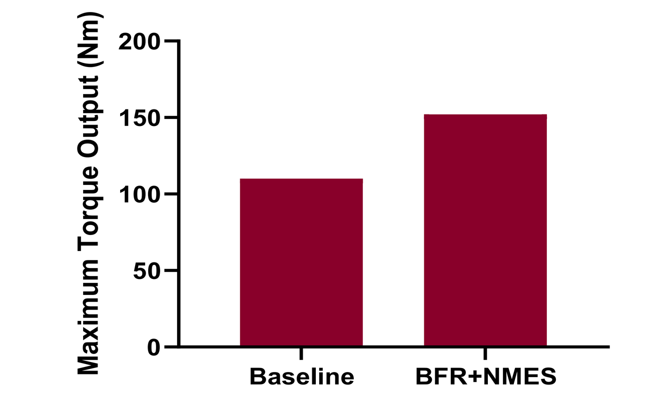


Figure 19: Maximum torque output

FUTURE DIRECTIONS

- User friendliness and accessibility
- Optimization of electrical stimulation parameters

CONCLUSION

The PLEIADES device, which provides blood flow restriction and neuromuscular electrical stimulation, can be used to enhance skeletal muscle adaptations during resistance exercise in long-duration spaceflight.

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QUESTIONS AND REFERENCES

All questions can be sent to the team lead Anaya Kashikar at akashikar@twu.edu.

All references can be found by scanning the QR code to the right.