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Self-Powered Microgravity Resistance Exercise with Soft Pneumatic Exoskeletons

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Abstract—**As preparations continue towards sending humans on a 3-year mission to Mars, space programs must find solutions to combat muscular atrophy experienced by astronauts during extended time in microgravity. One method currently used to combat muscle deterioration is daily resistance training sessions using an apparatus like the ARED or CEVIS exercise devices, but these daily exercise sessions are not expected to be enough to protect the muscles during longer missions. To help combat muscular atrophy, we propose self-resistance outside of the daily exercise sessions implemented through soft pneumatic exoskeletons that could be integrated into astronauts' suits, augmenting the formal exercise regimen to improve astronaut health during lengthy missions. To test the effects of self-resistance on muscle activity, we developed an elbow-elbow soft exoskeleton which we pressurized with air and connected to a closed fluid circuit so that as the user flexed their elbows, they were forced to work against themselves (self-resistance) via this column of air. In order to determine the effect of self-resistance, bicep muscle activity (obtained via surface electromyography) was recorded during horizontal motions with self-resistance and during both vertical and horizontal motions without self-resistance. Peak muscle activity and its variability both increased when self-resistance was applied, and correspondence between peak muscle activity and pressure indicates that the level of resistance could be tuned to achieve loads comparable to gravity. This soft pneumatic exoskeleton has the potential for easy integration into astronauts' suits and could reduce muscle deterioration in microgravity by engaging the muscles more consistently via self-resistance during daily tasks rather than only during specific exercise sessions.**

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1. INTRODUCTION

For astronauts in microgravity, the disuse of skeletal muscles leads to atrophy and deterioration, which can cause a substantial loss of muscular strength and functionality [1-4]. In addition to deterioration, the individual muscle fibers undergo shifts that remodel the muscle. This "microgravity-induced fiber type shift" [5] occurs when type I muscle fibers, which go largely unused in microgravity, shift to become type II muscle fibers. This shift is a main contributor to muscular endurance loss since type II fibers do not maintain high stamina. Upon reloading their muscles under the influence of gravity, astronauts usually experience weakness, soreness, and pain resulting from atrophied muscles. Research from missions aboard the International Space Station (ISS) shows that this muscular remodeling and deterioration becomes more substantial during longer duration missions, which usually last from six months to a year. Astronauts that spend an extended time in microgravity experience a substantial increase in fatigue and decrease in physical performance [5-7]. As preparations are made for astronauts to embark on roundtrip missions to Mars that include up to three years of space travel, developing and improving an effective method of protecting the muscular health of astronauts is becoming increasingly critical.

To reduce muscle fiber shifting and muscular atrophy, resistance training has become an established part of an astronaut's routine on space missions; the efficacy of this method has been demonstrated aboard the ISS. While in the microgravity environment, astronauts exercise for two and a half hours a day, six days a week, on one of three resistance machines: the Advanced Resistive Exercise Device (ARED), the Cycle Ergometer with a Vibration Insulation System (CEVIS), or the Treadmill with a Vibration Isolation System (TVIS) (note that this scheduled time includes tasks such as changing into exercising gear, setting up the machines, and cleaning up after exercise) [8]. These machines allow astronauts to perform numerous exercises targeting the lower body muscles, such as squats, deadlifts and calf raises, with applied levels of resistance relative to their body weight [8]. The different machines can apply various loads depending on what exercise is being performed. For example, the treadmill style machines typically load the equivalent of 70% of the user's body weight [9], while the ARED can provide a load up to and over 600 pounds [10]. With these varied loads, the resistance machines can increase muscle activity by creating loading conditions closer to those experienced on earth [9]. This applied load requires muscles to work against the resistance from the machines, engaging the muscles in conditioning exercises that help preserve strength,endurance, and more type I fibers.

The implementation of resistance training aboard the ISS has been able to mitigate, but not fully eliminate, muscular atrophy due to microgravity [5]. Muscular strength still decreases by up to 30% during a typical six-month mission in space [6]. For any mission longer than six months, muscular strength is expected to continue to decrease, creating greater problems for astronauts when they reload their muscles after entering environments with gravity [6-7]. One main reason that atrophy has not been further mitigated through resistance training is because only 7-10% of anastronaut's time in space is spent exercising due to necessity to perform other mission-related tasks and experiments [8]. Therefore, although resistance training can be a successful preventative method against atrophy, the time allotted for resistance training during a mission is not sufficient to fully protect astronauts' muscles during long missions to Mars.

A suggested method for further engaging muscle movements in microgravity outside of periods spent on specialized machinery is the introduction of a resistive exoskeleton. The use of exoskeletons has already been applied to the postflight rehabilitation of astronauts. An example is NASA's X1 lower body exoskeleton, which was designed to help with zero-gravity assistance control, gait rehabilitation, and assisted walking for returning astronauts [11]. The success of exoskeletons on the ground has led to the idea of integrating exoskeletons into the suits of astronauts to support key muscle groups while in microgravity. An integrated resistance exoskeleton would allow "continuous all-day training of all body segments" [6] by introducing a resistive force that emulates a continuous load on the muscles like the one experienced on Earth. Rather than restricting muscle conditioning to certain hours spent on exercise machines, exoskeletons can allow mobility and comfort while providing muscle resistance during daily activities.

Building on the idea of implementing resistance exercise during daily activities with an exoskeleton [11], we propose a soft pneumatic exoskeleton with two distinct features: (1) pressurized actuators to create a tunable level of resistance based on the pressure and (2) interconnection of the actuators to implement self-resistance, causing the user to work against him/herself. Implementation of self- resistance during daily activities can activate muscles outside of the formal exercise schedule. Resistance to typical muscle movements will keep the muscles engaged for longer periods of time in loading conditions that more closely resemble those on Earth, reducing deterioration and fiber shifting.

In this preliminary study, we chose to focus on the examination of peak muscle activity in the upper body to assess the effects of the fluid actuator-aided self-resistance exercise paradigm more simply; this choice allowed us to easily remove gravitational effects and isolate muscle groups in ways that would have been more difficult with lower-limb devices. To execute this goal, we designed a soft pneumatic elbow-elbow exoskeleton that resisted movement initiated by the biceps brachii. Self-resistance was created by connecting the actuators on both elbows through a closed fluid circuit; as the user flexed their elbows, they were forced to work against themselves through the column of air contained within the exoskeleton's circuit.

Muscle activity for the biceps brachii on both arms was recorded using electromyography (EMG) during vertical and horizontal bicep curls. A basis for bicep muscle activity wasestablished with vertical bicep curls (muscle activity versus gravity) which was used to normalize all subsequent tests involving horizontal bicep curls (muscle activity isolated from gravity) performed with and without the exoskeleton. Section 2 describes the construction and development of the soft pneumatic exoskeleton using rotary

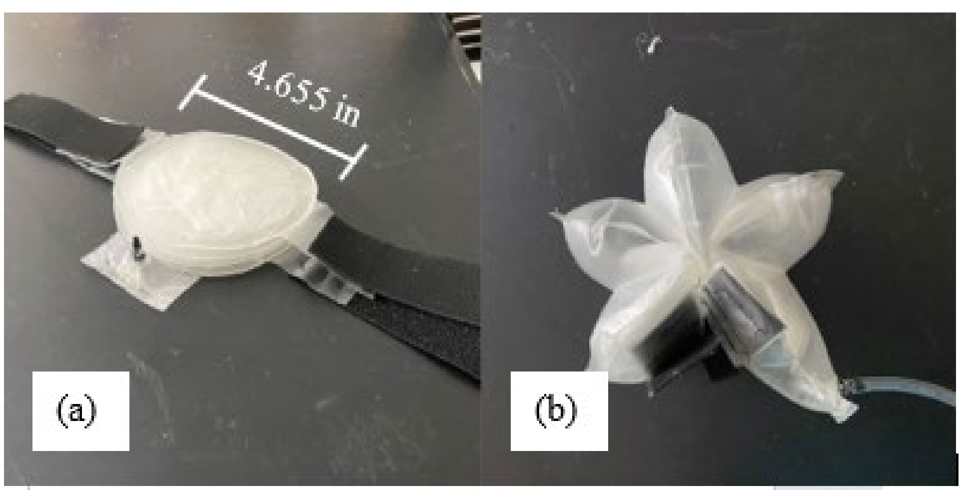

Figure 1. TPU rotary bellow actuators with a total of 5 chambers. (a) Deflated rotary actuator. The chamber on top has two straps and the chamber on bottom has two straps for attachment to the arm. (b) Inflated rotary actuator with the 5 expanded chambers to extend the arm to close to 180 degrees when inflated.

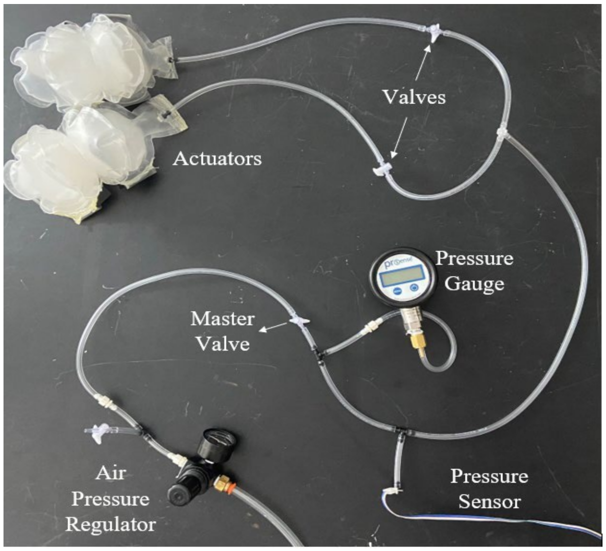

Figure 2. Closed fluid circuit through which self-resistance is transmitted by pressurizing the exoskeleton. Separate on/off valves control air flow into each actuator. A junction connects the air flow of both actuators when the valves are opened. A master air valve controls the air flow into the whole circuit from the pressure regulator. When pressurized, the closed fluid circuit forces the user to work against the column of air in the circuit to flex both elbows simultaneously.

bellow actuators, as well as the procedures used to perform subject testing. The results presented in Section 3 demonstrate the relationships between bicep muscle activity and different conditions with and without the exoskeleton and self-resistance.

2. MATERIALS AND METHODS

Exoskeleton Fabrication

The self-resistance pneumatic exoskeleton employed in this study consists of the two bellow actuators, depicted in Figure 1, which can be connected via a closed fluid circuit (Figure 2). The actuators are designed as a series of connected chambers fixed together at a joint on one side so that they induce rotation as they inflate. The actuators are each made of five chambers which, when inflated, can extend the arm to180 degrees, as seen in Figure 3.

The primary material used to fabricate the actuators was Perfectex ET20-C30 0.3mm thick Ether Thermoplastic Polyurethane (TPU). Layers of TPU and glassine paper were cut to the appropriate shape and size using a Cricut Maker[1]. To fabricate each actuator, the TPU layers were sealed together around the glassine paper masks to prevent bonding within the chambers and at the edges using a MPress Heat

Figure 3. Rotary actuator attached to the arm using Velcro straps around the upper arm and the forearm with the central joint sitting in the bend of the elbow. (a) Deflated actuator attached to the arm. (b) Fully expanded, the actuator extends the arm out horizontally to reach around 180 degrees. (c) Placement of the Velcro straps on the forearm and upper arm during human subject testing.

Press at 325°F for approximately 45 seconds. Once sealed, an air fitting was attached to the actuator to allow an air hose to be connected. During the fabrication process, four TPU strips were heat pressed into the sides of the first and last chambers of the actuator. Velcro straps were then sewn directly onto these four strips to allow the device to be securely fastened to the user, as well as be adjustable to accommodate different arm sizes. The actuators were affixed to the user by attaching one set of Velcro straps to the upper arm and the other to the forearm. The placement of the straps was such that the joint around which the chambers opened was sitting in the bend of the elbow (Figure 3).

An elbow-elbow exoskeleton was constructed by connecting the two actuators to a network of tubing and valves to create a closed fluid circuit (Figure 2). Within this circuit, the actuators were connected to independent air valves so that each device could be inflated separately. A junction connected the two air valves so that air would flow between the actuators during self-resistance testing. This junction was connected to two pressure instruments: a digital pressure gauge and a pressure sensor (Honeywell SSC Series TruStability, 0-1 bar, analog output) measured pressure values in the tubing between the two actuators. The pressure sensor recorded the pressure in the fluid circuit during the tests to display how pressure responded to the compression of the exoskeleton when using self-resistance.

[1] Design can be found at: https://design.cricut.com/landing/project-detail/60c22a176ed7d20944d3cf26

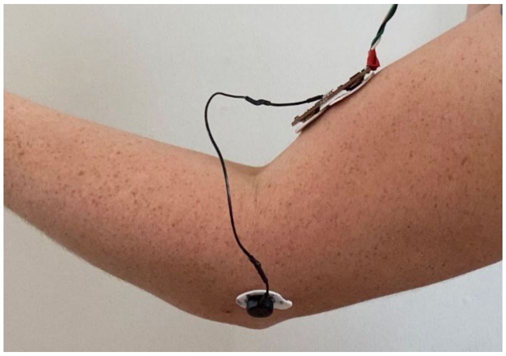

Figure 4. Placement of EMG sensors. The bottom electrode was placed on the muscle belly of the biceps brachii, which was found by having the subject flex the muscle, while the reference electrode was placed on the bony section of the outer elbow.

The air flow for the whole circuit was controlled by a master valve connected to an air pressure regulator. To create the pressurized self-resistance during the tests, the master air valve was closed after the actuators were pressurized while the two valves connected directly to the inflated actuators were open, allowing air to flow in between the two devices.

Human Participant Testing

To evaluate the effect of self-resistance on muscle activity, a series of human participant tests were completed with and without the elbow-elbow exoskeleton, under a protocol approved by the Trinity University Institutional Review Board. All participants signed a written informed consent form. The tests were designed to compare the levels of muscle activity experienced during exercises with self-resistance to exercises without resistance, as well as understand how muscle activity against self-resistance compares to typical muscle activity under the influence of gravity.

The muscle activity for each bicep was measured during the tests using EMG sensors: a MyoWare muscle sensor was placed on the muscle belly of each bicep with the outer elbow used as the reference, as seen in Figure 4. Data was logged using Matlab/Simulink Desktop Real Time at a frequency of 100 Hz, since prior work with MyoWare EMG sensors, illustrated that signals roll off beyond 50-60 Hz [12]. Compression sleeves were used during all tests, including tests without the exoskeleton, to protect the EMG sensors from rubbing against the actuators and to prevent the actuators from rubbing directly onto the user's skin. During preliminary tests to verify the function of the sensors, we did not see any indications that EMG readings were influenced by pressure from the exoskeleton or compression sleeves.

Participants — Five able-bodied participants (three females and two males; age: 23.6 ± 4.9) took part in this study. All five participants reported to be right-hand dominant. A total of six conditions were performed, and each participant repeated the experiment on two different days. To account for the differences in EMG readings due to possible varied placement of the electrodes and different gain levels in the readings, the tests were normalized to a baseline test

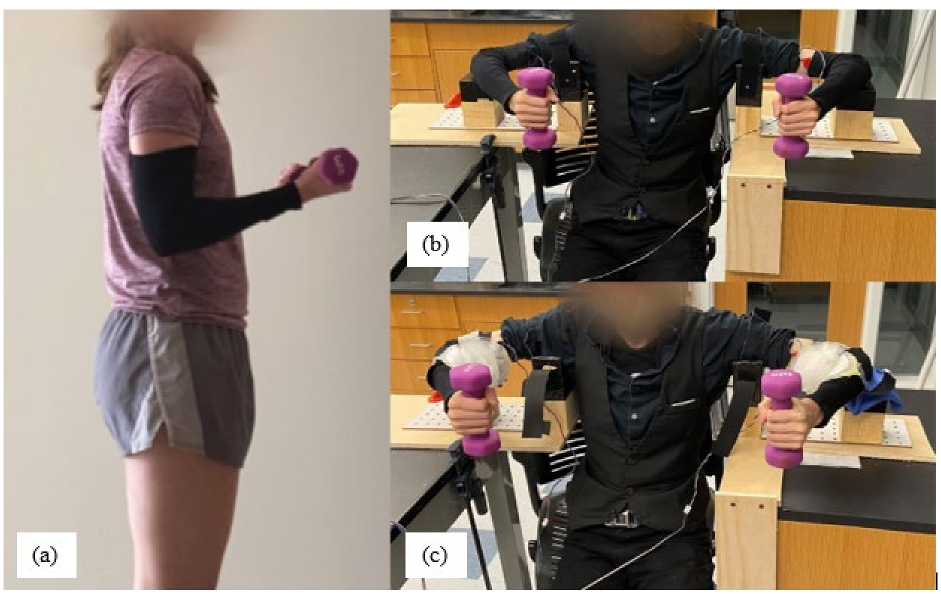

Figure 5. Testing positions performed by participants. (a) Vertical bicep curls: participant lifts forearms vertically to just past 90 degrees while keeping the upper arms stationary. Both hands are lifted at the same time, each holding a 3-lb weight. (b) Horizontal bicep curls without resistance: participant rotates both forearms inward towards the chest to just over 90 degrees while holding 3-lb weights and sitting in the designated testing station. (c)Horizontal bicep curls with exoskeleton: The exoskeleton is worn by the participant. The curls are first performed with no pressure, and then again with pressurized actuators, both while holding 3-lb weights.

performed by the same participant on that given day, since the sensors were not removed between tests or trials on a single day. The normalization of data is further discussed at the end of this section. All participants were non-naïve to some degree: two of the participants were the authors of this study, while the other three were part of the same lab and therefore had limited knowledge about the goal of the tests.

Vertical Bicep Curls — To establish a basis for typical bicep muscle activity against gravity, participants were instructed to perform ten vertical bicep curls with three-pound weights while wearing only the sensors and compression sleeves. To execute a curl, participants started with their hands hanging by their sides, palms out, and raised their forearms to just above 90 degrees while keeping their upper arms still, as depicted in Figure 5a. Participants were instructed when to raise, hold, and release the curl to allow the signals to steady before each curl.

Horizontal Bicep Curls — Following vertical bicep curls, three sets of horizontal bicep curls were performed in a seated testing station (see Figure 5b and 5c). To simulate microgravity within the limitations of an earthbound laboratory, this station consisted of two arm rests and two elbow rests to support the arms against gravity, enabling participants to perform horizontal curls with minimal influence from gravity on the bicep muscle activity. Participants placed their arms in the supports as close to the armpit as possible and were strapped in with Velcro straps. The elbow rests were moved to the appropriate distance to accommodate different arm sizes.

Once seated, the participant performed horizontal curls under three different conditions: without the exoskeleton (NoExo), wearing the exoskeleton with uninflated actuators kept open to atmospheric pressure (ExoOnly), and wearing the exoskeleton with self-resistance (ExoResist). For each condition, the participant was instructed to perform ten horizontal bicep curls while holding three-pound weights. The participant started with their arms straight out horizontally and curled inward towards their chest until they just passed 90 degrees.

Self-resistance was introduced during the ExoResist condition when the actuators were attached to the closed fluid circuit (Figure 2). Before testing, each actuator was inflated to 2 psi and then closed off from the circuit with the air valves. Once inflated, the placement of the actuators was visually verified by the experimenter to ensure that, during the exercise, the devices were not hanging below or pushing above the arm. Testing began after the air valves connecting the actuators were opened, allowing the circuit to equalize at a starting pressure reading for the pressure sensors. By leaving the master switch closed,a column of air contained between the two actuators introduced self-resistance to the bicep muscles when curls were performed.

Data Analysis

The signals from the EMG sensors were already internally amplified, rectified, and enveloped, so no additional processing was performed (more information can be found on these sensors in [12]). On each day, the mean peak muscle activity during the vertical curls for each participant was used to normalize the three subsequent horizontal curl tests for the same participant, such that a value of 1 corresponds to the same peak muscle activity as observed during the average vertical curl.

3. RESULTS

All the following results for the bicep curls are expressed in terms of normalized EMG readings, where a value of 1 is equal to mean peak muscle activity recorded during vertical curls for that participant and day, as described above. This section provides a summary of the findings; these trends are further discussed and analyzed in the Discussion that follows.

Peak bicep muscle activity was analyzed by averaging the ten curl repetitions performed by each participant on each day and the resulting averages are displayed in Figures 6-7. The standard deviation across the ten repetitions for each subject is expressed in the form of error bars to illustrate the variability of muscle activity.

For the left arm, a repeated measures (within subjects) analysis of variance (ANOVA) on the normalized muscle activity across all 20 repetitions (both days) revealed significant effects by condition (p = 8.96e-04, $F(2.23, 220.4) = 1.75$ with a Greenhouse-Geisser correction to adjust for lack of sphericity). A post-hoc multiple comparison test revealed significant differences at a 95% confidence level between vertical curls and ExoOnly ($p = 0.049$), between NoExo and ExoResist ($p = 0.009$), and between NoExo and vertical curls ($p < 0.001$). For the right arm, a similar analysis also revealed significant effects by condition (p = 5.54e-06, $F(1.85,183.5) = 4.17$). The post-hoc multiple comparison revealed significant differences between the ExoOnly and NoExo conditions, between NoExo and ExoResist, and between NoExo and vertical curls (each with $p < 0.001$).

The error bars in the results demonstrate how the two sets of curls involving the exoskeleton had greater variability for most participants and for both arms. To further illustrate this variability, Figure 8 shows the peak muscle activity for each repetition and condition from a representative participant.

Figure 9 is an illustrative result of the relationship between peak muscle activity during self-resistance and peak pressure for a single participant test. The peak pressure measurements recorded during the self-resistance exercises were shown to correspond with the peaks of muscle activity

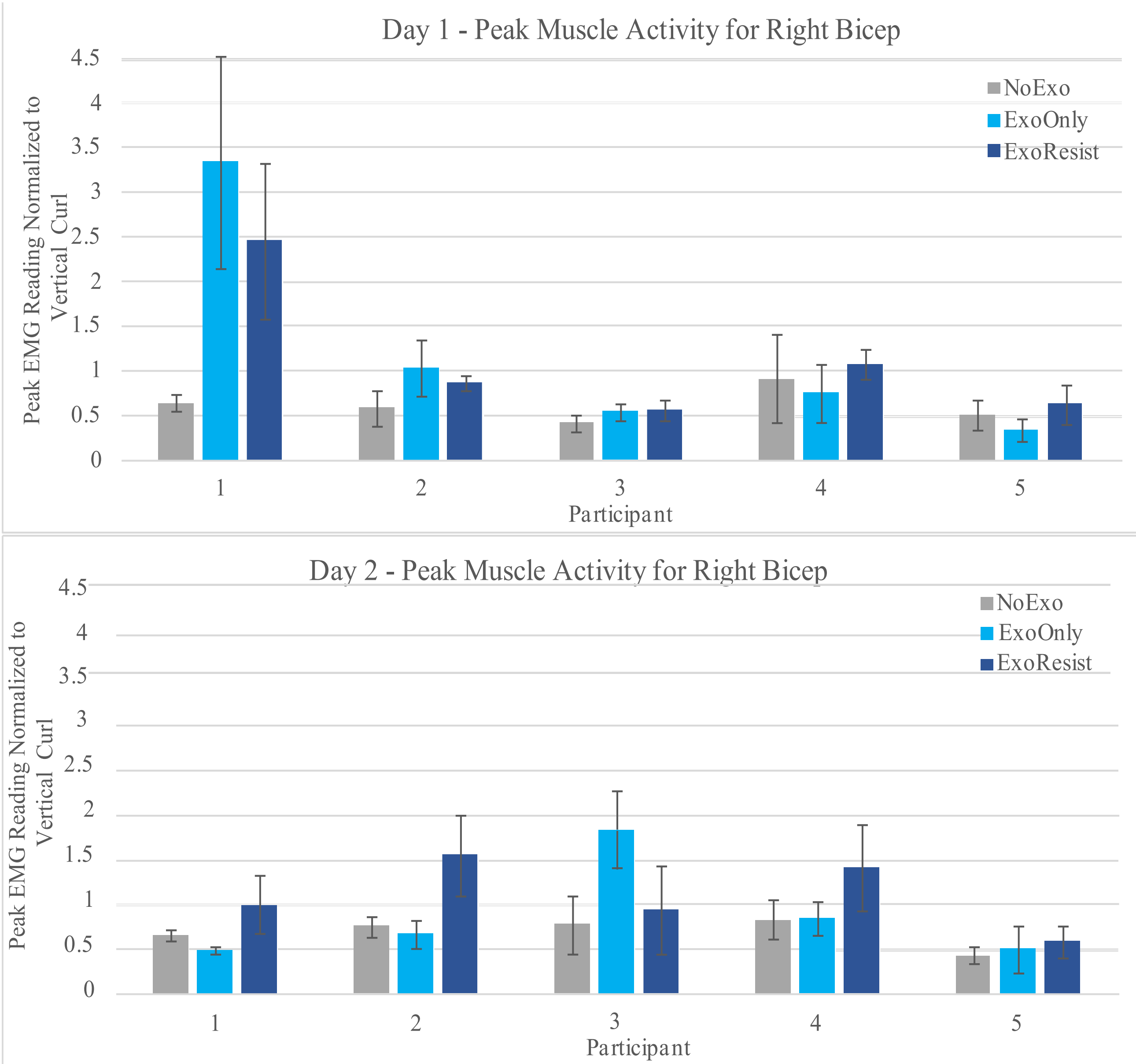

Figure 6. Mean peak muscle activity for the right bicep for each subject from the first (top) and second (bottom) day of testing. Results for each condition are normalized against vertical curl peak muscle activity for that day. The x-axis shows the participant number, and error bars represent 1 standard deviation across the 10 repetitions.

in both arms, as depicted by the dotted lines in Figure 9. It was generally observed that peak pressure tended to decrease over the course of the tests with the ExoResist condition, which can be seen by the gradually decreasing peaks for the pressure in Figure 9. The average peak pressure across all participants and trials was calculated to be 1.35 psi (9.12 kPa), as demonstrated by Figure 10.

4. DISCUSSION

Vertical Curl vs. Horizontal Curl Comparison

The data presented for the right arm in Figure 6 demonstrates how the NoExo readings were always below a value of 1, meaning that the horizontal curls required less muscle activity than the curls performed against gravity, which was found to be statistically significant difference. Figure 7 shows that this trend was the same for the left bicep for all but one participant in the first trial and still demonstrated a statistically significant difference between the two conditions. When comparing the ExoOnly and ExoResist condition for the right bicep (Figure 6) to their measurements on the y-axis, the EMG readings oscillated around the value of 1, with no consistent pattern. For the left bicep (Figure 7) ExoOnly was significantly lower than 1 statistically, while ExoResist was not.

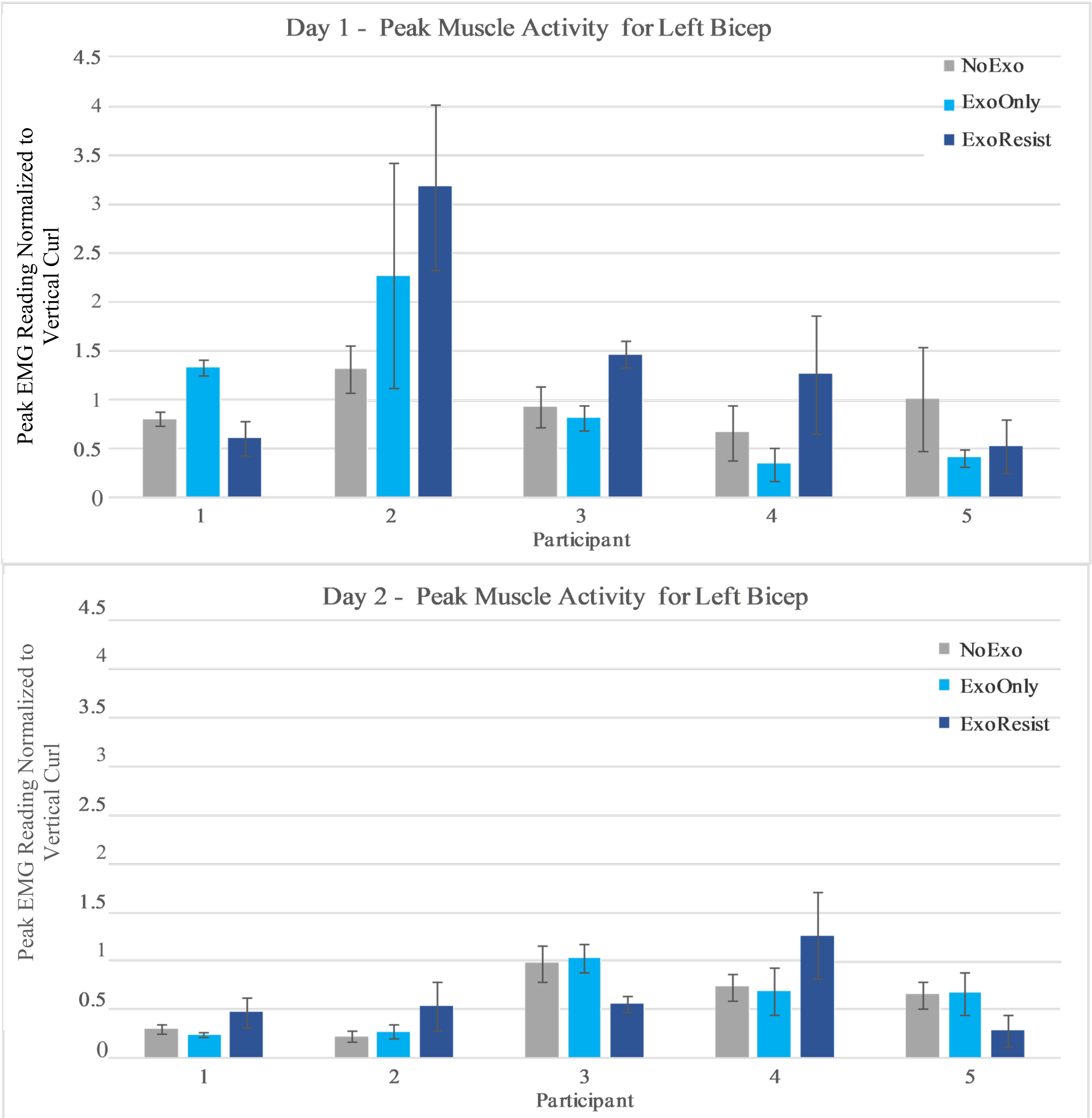

Figure 7. Mean peak muscle activity for the left bicep for each participant from the first (top) and second (bottom)of testing. Results for each condition are normalized against vertical curl peak muscle activity. The x-axis shows the participant number, and error bars represent 1 standard deviation across the 10 repetitions.

Efficacy and Applications of Pneumatic Exoskeleton

Influence of the Exoskeleton on Muscle Activity — The results for the ExoOnly tests in Figures 6 and 7 (light blue bars) demonstrate that there was no clear pattern for the peak muscle activity while the deflated exoskeleton was worn. Muscle activity varied across participants and days, with peak measurements being both above and below the NoExo (gray) and the ExoResist (dark blue) measurements, though when accounting for participant-to-participant differences ExoOnly was statistically different from NoExo for the right arm only. Surprisingly, six of the twenty normalized averages depicted across Figures 6 and 7 demonstrated that ExoOnly curls generated more muscle activity than ExoResist. A possible explanation for the varied ExoOnly measurements could be that participants adjusted their muscle movements when wearing the exoskeleton for the first time, and either under or overcompensated their muscle activation during the curls.

The fluctuations in the ExoOnly muscle activity can be further seen in the peak muscle activity for each

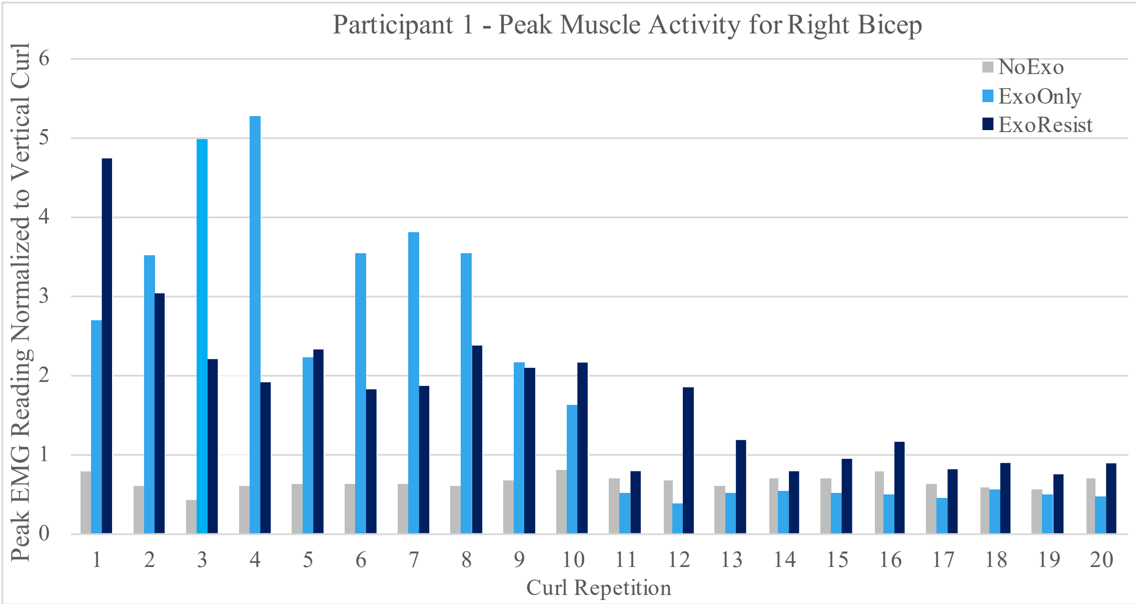

Figure 8. Mean peak muscle activity for Participant 1's curl repetitions during the NoExo, ExoOnly and ExoResist conditions for the right bicep on each day. Bar graphs show the breakdown of average peak muscle activity for each repetition, with the first 10 reps from Day 1 and the second set of 10 reps from Day 2. The muscle activity was normalized against vertical muscle activity, where 1 on the y-axis represents the value of mean peak muscle activity during vertical curls from that day.

participant's individual curl repetitions. Figure 8 shows the specific data for the right bicep from participant 1, demonstrating how theExoOnly peak muscle activity for the right bicep was both higher and lower than the NoExo and ExoResist measurements across the twenty repetitions.

Ability of self-resistance to increase muscle activity — Self- resistance increased muscle activity when compared to the NoExo condition in most cases, particularly for the right arm. Figures 6 depicts that all participants demonstrated higher peak muscle activity in the right bicep during the ExoResist condition when compared to the NoExo condition on both days, and Figure 8 shows the same trend for a representative participant. This difference between the NoExo and ExoResist conditions was found to be statistically significant. Results were less consistent for the left bicep (Figure 7), but still demonstrated a statistically significant difference between the NoExo and ExoResist conditions. The ExoResist peak muscle activity was greater than the NoExo condition for three out of the five participants on each day, although the specific participants exhibiting this trend changed across the two days (on Day 1, participants 1 and 5 demonstrated a higher peak activity during NoExo curls, while on Day 2, participants 3 and 5 demonstrated higher activity during NoExo curls). We hypothesize that the differences between the bicep results across arms are due to the fact that all participants were right arm dominant, which may have affected the way participants used their muscles during curls.

Since we did not record elbow angle during the tests or enforce a specific angle other than in the initial instructions, there is no way to determine how the motion differed betweenthe two arms in each condition, creating more consistent results in the right arm. However, the statistically higher peak muscle activity in the ExoResist vs. NoExo conditions for both arms indicates that self-resistance has the potential to increase peak muscle activity of the bicep in an environment isolated from gravity.

Comparison to gravitational loading — The ExoResist measurements (dark blue) in Figures 6 and 7 have values both above and below 1. This indicates that the ExoResist condition did not always reach or surpass the peak muscle activity required to perform curls against gravity; however, the values were close enough to vertical curls to prevent a significant difference between the vertical curl and EcoResist conditions. Since we observed that peak muscle activity corresponded with the peak pressure (Figure 9), adjustments can be made to the pressure to increase the necessary self-resistance, and thus more closely resemble the typical loading effect of gravity.

Variability in muscle activity — The two conditions that required the exoskeleton (ExoOnly and ExoResist) were shown to have higher variability in the peak muscle activity. The contrast between the variability in muscle activity during NoExo and the other two conditions can be seen clearly in the representative results from participant 1 in Figure 8. The differences between each peak measurement for each repetition during the ExoOnly (light blue) and ExoResist (dark blue) conditions tended to be larger on both days than the NoExo (gray) condition. Although the size of the variability changed between days, especially for the ExoOnly condition, both sets of curls

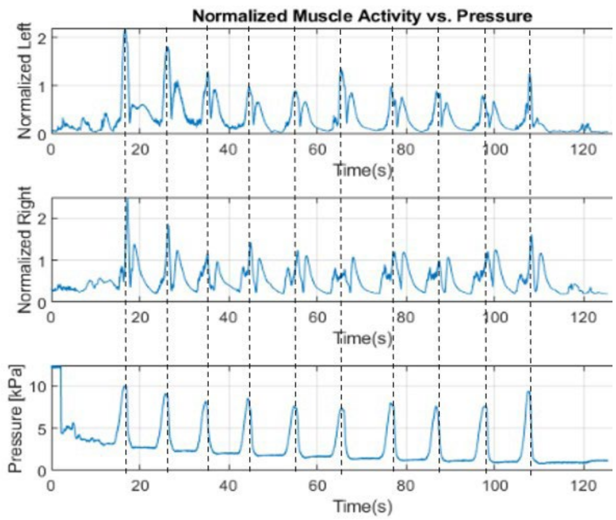

Figure 9. Normalized muscle activity for each bicep andpressure sensor readings during bicep curls from the ExoResist condition for Participant 4. Each peak in muscle activity corresponds with a peak in the pressure.

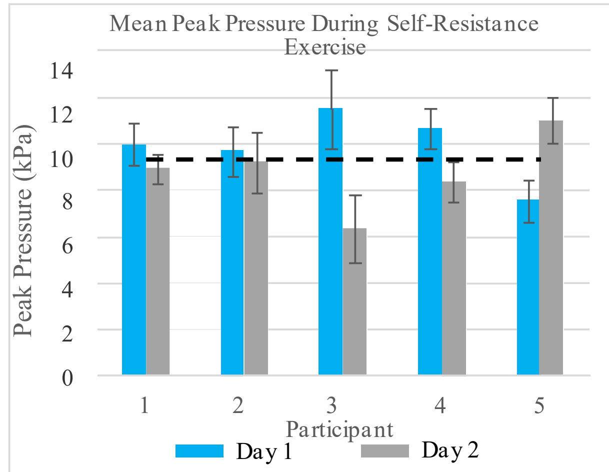

Figure 10: Bar graph showing the mean peak pressure from each trial for each participant. The dotted line shows the overall average peak pressure of 9.29 kPa (1.35psi) produced by the exoskeleton during horizontal bicep curls across all participants.

with the exoskeleton still have larger fluctuations between peak measurements than the curls without the exoskeleton. For all participants, the same trend can be seen in the size of the error bars in Figures 6 and 7: most participants demonstrated more variability during the ExoOnly or ExoResist conditions (or both) than the NoExo condition. This increased variability suggests that the addition of both the exoskeleton and self-resistance caused participants to push against the exoskeleton and engage their biceps in different ways and at different levels of activation.

Limitations

For this pilot test, we were focused on providing a general picture of how self-resistance influenced low frequency movements. We used a sampling frequency of 100 Hz for the EMG sensors to perform this test. However, we acknowledge that this frequency is inadequate for EMG data collection. As we move forward with this project, we intend to increase this sampling frequency to be able to go deeper into the data and have a more detailed analysis.

5. CONCLUSION

To be an effective solution for combatting muscular atrophy in microgravity, the pneumatic exoskeleton should increase muscle activity experienced in the absence of gravitational loading. In this study, by using the horizontal plane as a proxy, we were able to observe the influence of self-resistance on the biceps brachii muscle while isolated from the loading effect of gravity. The results from the tests involving an inflated exoskeleton successfully demonstrated that the addition of self-resistance can significantly increase peak muscle activity when isolated from gravity (NoExo vs. ExoResist). Wearing the exoskeleton during self-resistance was also shown to increase the variability in muscle activity. These observed trends provide a preliminary understanding of the influence of self-resistance on muscle activity and can be further expanded to successfully design and implement a new form of resistance training for astronauts.

Several limitations of this preliminary work motivate the need for future development and study of self-resistance exercise. All participants were non-naïve, which may limit repeatability, as well as right hand dominant, which may have influenced the trends that were observed. Furthermore, this was a preliminary exoskeleton design, and future development of both the technology and testing procedures is needed, including an increased sampling frequency for the EMG data. As we continue to study the potential of self-resistance, we intend to test with a larger sample size and more naive population, as well as explore connections between additional muscle groups through additional actuators. In addition to more actuators, the introduction of solenoid valves into the fluid circuit would allow control over which muscles work against each other in the same manner that has previously been proposed selecting which muscles might assist each other in a passive exoskeleton [13]; this would enable the user to reduce, increase, or completely shutoff the self-resistance in their suit for certain situations whereadded resistance is not needed or desired, such as extravehicular activity. Being able to control the level of resistance will directly rely on the relationship between pressure and mean peak muscle activity.

This preliminary study proposed a method for enabling self-resistance via a pneumatic exoskeleton. Self-resistance using a pneumatic exoskeleton was shown to increase muscle activity in most cases in the horizontal plane when compared to muscle activity without self-resistance. Self-resistance could be integrated into the suits and attire worn inside the spacecraft during long duration missions to increase muscle activity during daily flight activities to maintain muscle endurance, strength, and function by engaging the muscles more.

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