Characterization of Joint Resistance and Performance Degradation of the Extravehicular Mobility Unit Spacesuit: A Pilot Study

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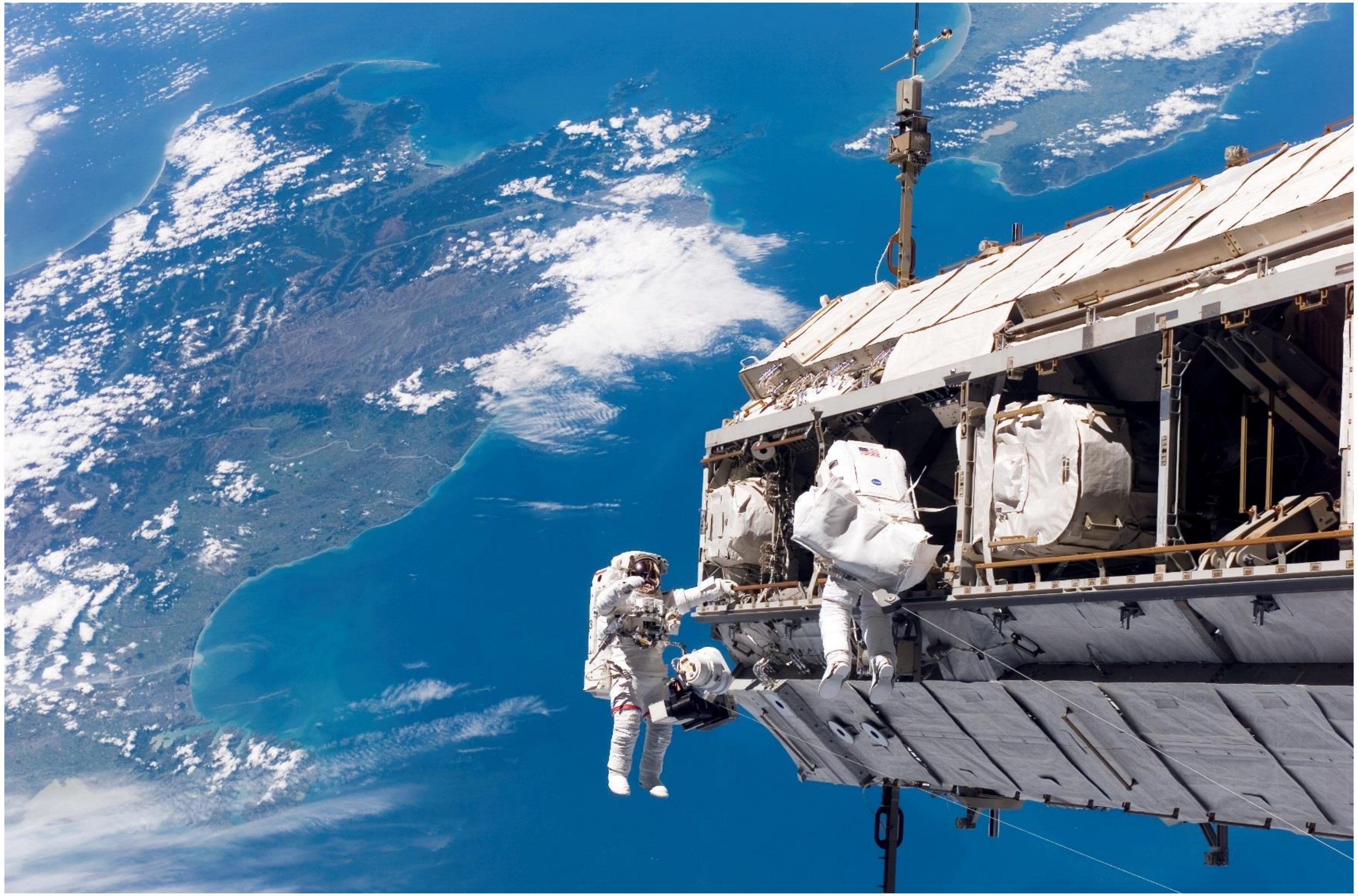
Overview

- Background
- Project Objectives
- Methodology
- Results
- Discussion
- Future Work

Background

- Environmental
  - Microgravity
  - Radiation
  - Contamination
  - Extreme Temperatures
- Physical
  - Physically Demanding Work
  - Spacesuit



Background – Extravehicular Mobility Unit

- Extravehicular Mobility Unit (EMU)
  - Pressurized personal protective suit.
  - Protects astronauts from the harsh environment of space during Extravehicular Activities (EVA).
  - Components
    - Helmet
    - Hard Upper Torso
    - Arm Assemblies and Gloves
    - Lower Torso Assembly
    - Leg assemblies and Boots

Background – EMU Exposure

- Use of the EMU is not limited to space operations.
- Significant amount of pre-mission ground based training.
  - EVA basic skills training
  - EVA mission specific training
- Cumulative suited pre-flight training time can exceed 300 hours
- Between flights, familiarization training is regularly performed to maintain suit skills.

Background – EMU Exposure

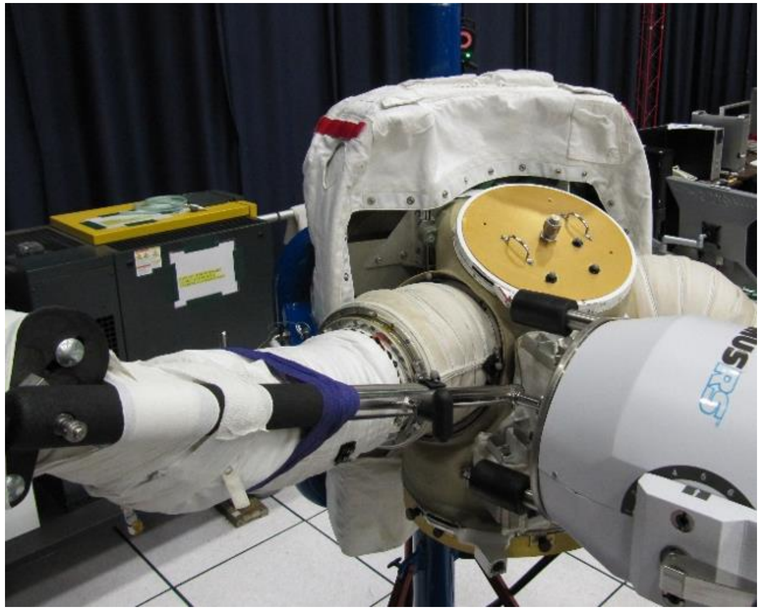
- Observed association between EVA training time and musculoskeletal injuries.
    - Restricted ROM, suit contact, improper suit fit.
- Previous work
    - 50% reduction in isolated joint strength.
    - Significantly reduced work output.
- Recent work
    - May be instances of improved strength performance depending on movement direction.

Objectives

1. Quantify the resistance to movement generated by the EMU upper arm assembly.
2. Characterize human strength performance degradations caused by the pressurized EMU.

Methods – EMU Upper Arm Assembly Resistance to Movement

- Unoccupied pressurized HUT and upper arm assembly
- Joint rotation axis aligned with dynamometer
- Shoulder Abd/Add
- Elbow Flx/Ext
- 90^{o} arc at 60^{o}/sec.

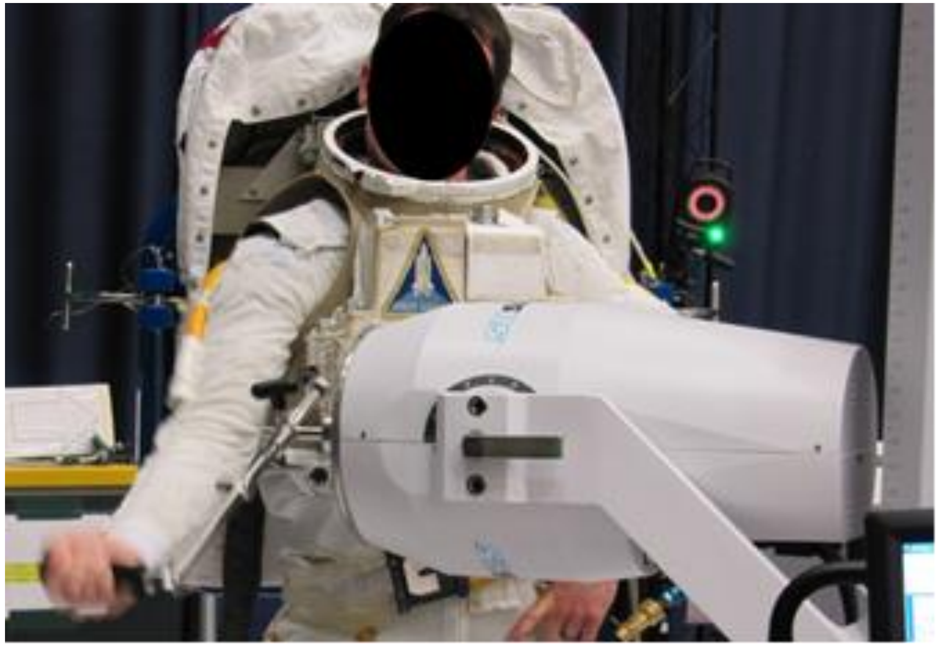


Methods – Human in the Loop Strength Assessment

- 5 Male subjects (age 31.8 ± 7.2)
- Isokinetic arm movement
  - Shoulder Abduction-Adduction
  - Elbow Flexion-Extension
- 1 Trial of each movement
  - 4 repetitions
  - 1st was considered familiarization
- Suit Conditions
  - Unsuited (secured in chair)
  - Suited Un-Pressurized (EMU HUT without arm assemblies)
  - Suited Pressurized (Full EMU pressurized to 29.6 kPa differential)

Methods – Suit Conditions

Unsuited

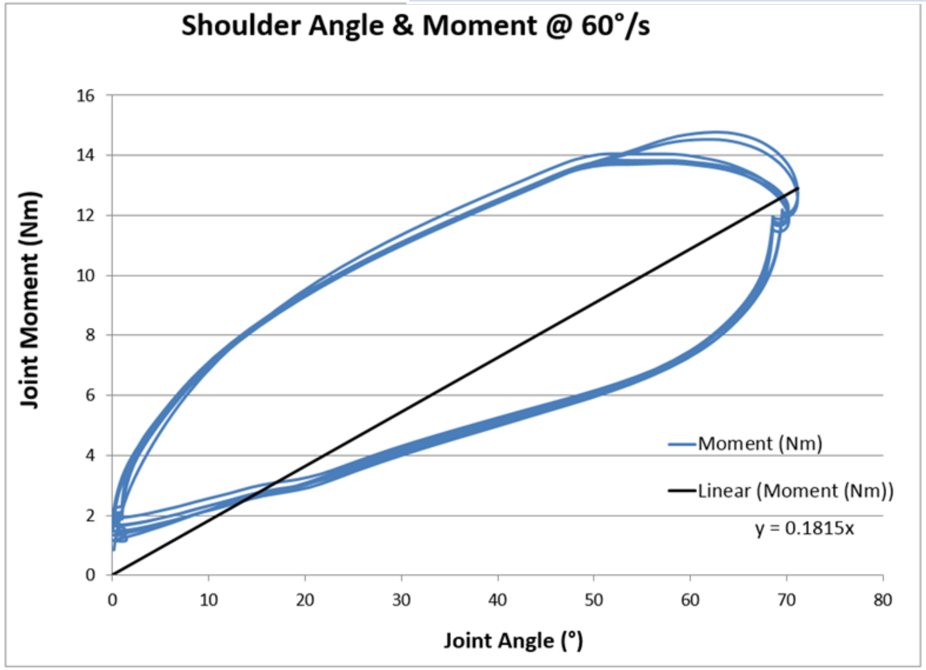


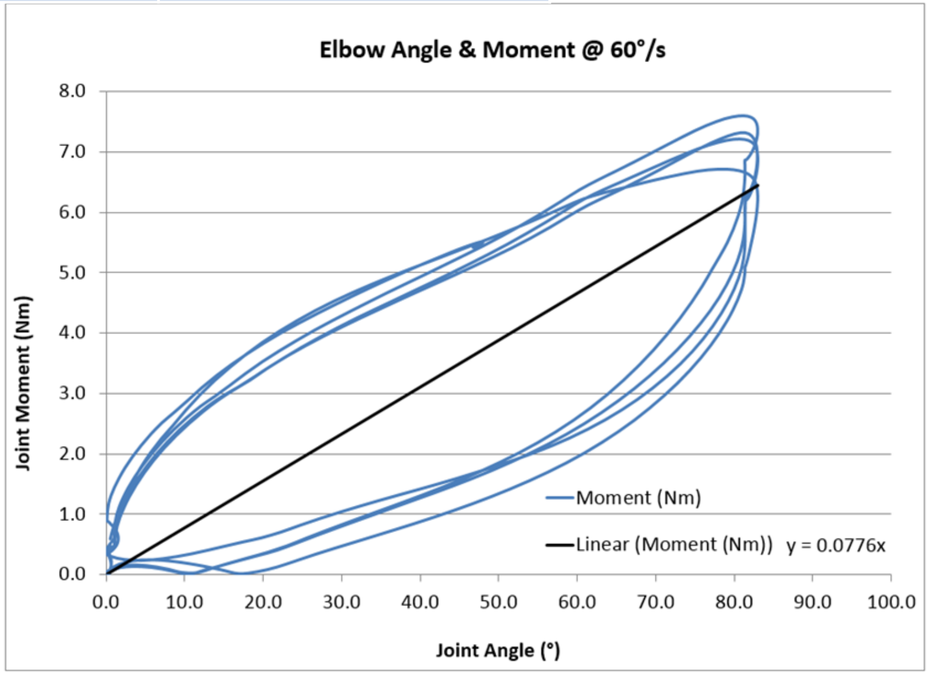
Suited Un-Pressurized

Suited Pressurized

Results – Suit Joint Resistance

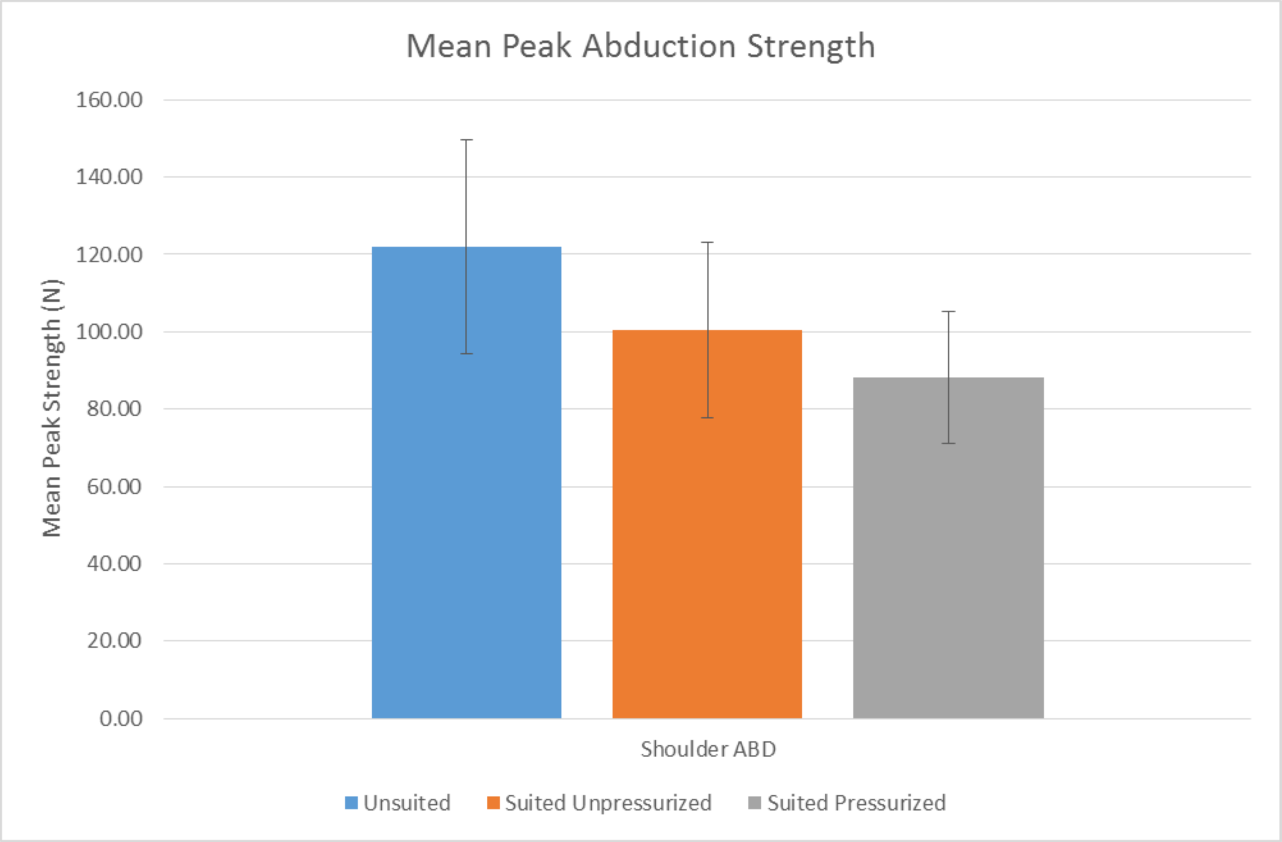
EMU Resistance to Movement (Nm)		
Joint Movement	**Max**	**Mean (sd)**
Shoulder Abduction	23.7	11.9 (8.2)
Shoulder Adduction	20.3	12.0 (6.8)
Elbow Flexion	26.0	12.3 (9.2)
Elbow Extension	24.9	10.8 (8.9)





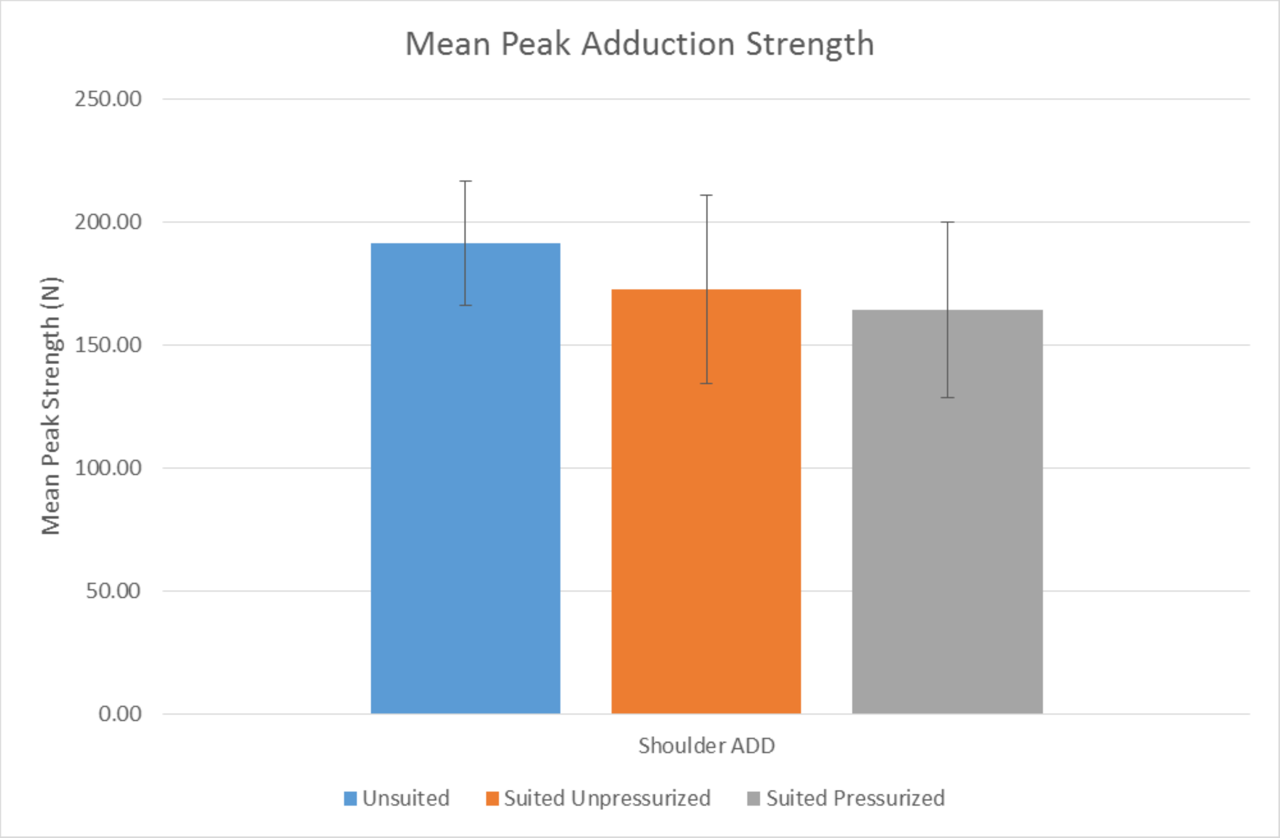
Results – Strength Assessment

- Shoulder Abduction
  - Significant mean peak strength differences between suited conditions ($F(2,28) = 6.9$, $p < 0.01$)
    - Unsuited > Suited Pressurized ($p = 0.01$)
  - Practical Differences
    - Determined to be practically different if greater than 15% difference
    - Unsuited > Suited Un-Pressurized (18%)



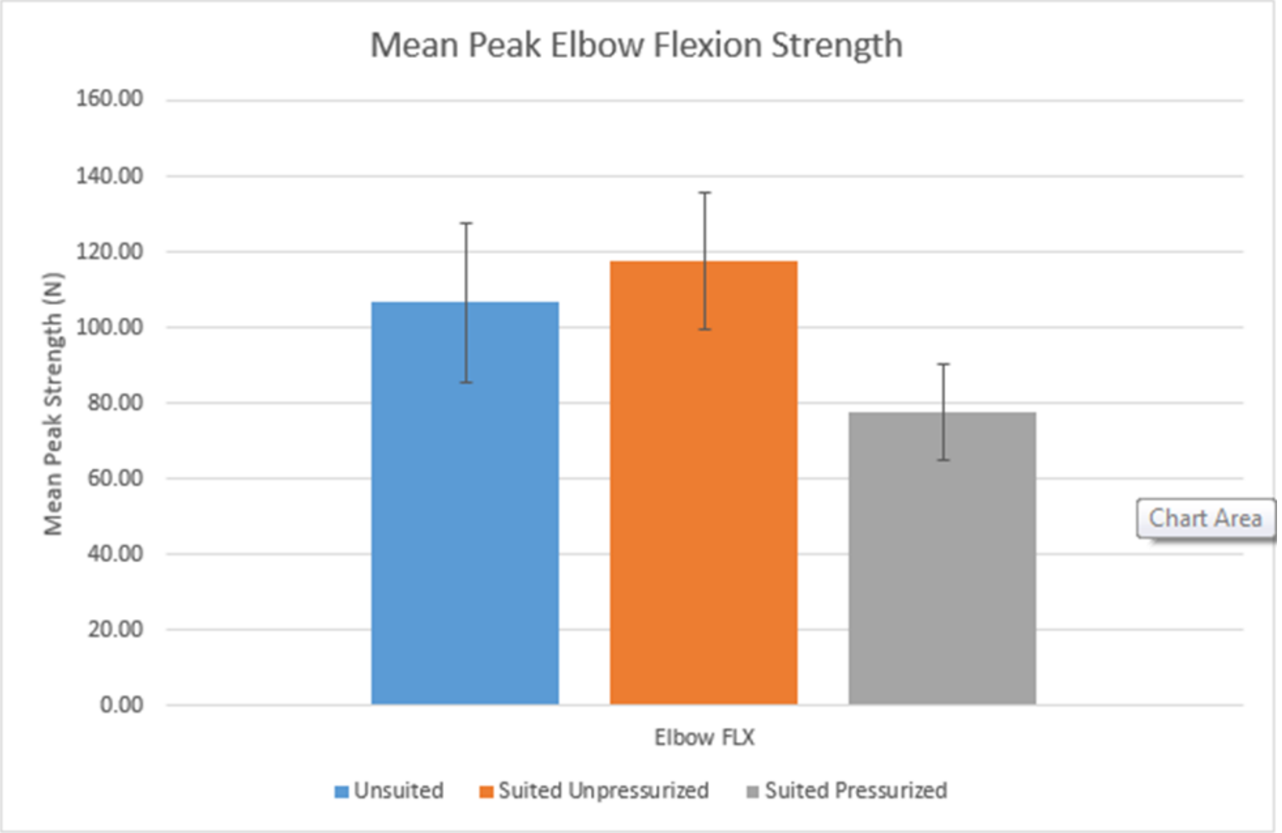
Results – Strength Assessment

- Shoulder Adduction
  - Significant mean peak strength differences between suited conditions ($F(2,28) = 7.02$, $p < 0.01$)
    - Unsuited > Suited Un-Pressurized ($p = 0.03$)
    - Unsuited > Suited Pressurized ($p < 0.01$)
  - No practical differences were noted



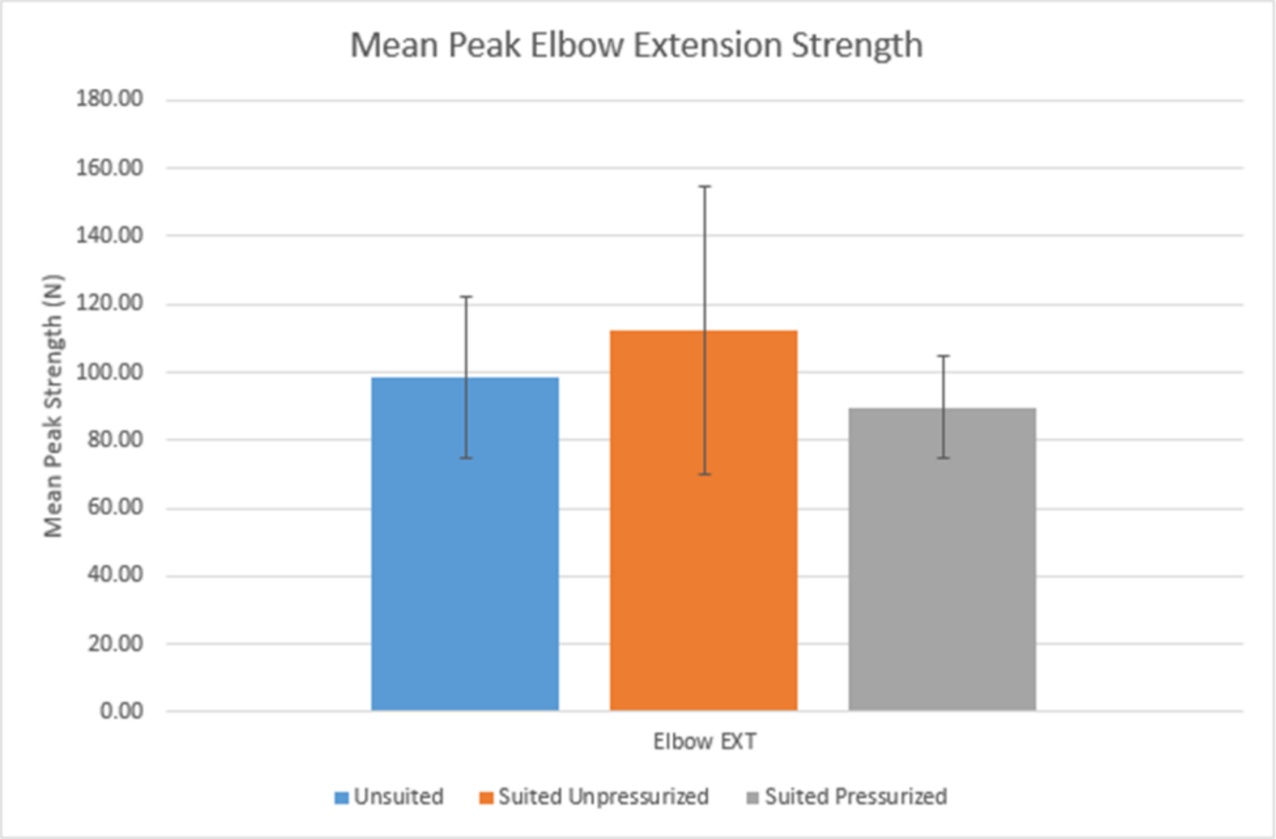
Results – Strength Assessment

- Elbow Flexion
  - Significant mean peak strength differences between suited conditions ($F(2,28) = 35.56$, $p < 0.01$)
    - Unsuited > Suited Pressurized ($p < 0.01$)
    - Suited Un-Pressurized > Suited Pressurized ($p < 0.01$)
  - No practical differences were noted



Results – Strength Assessment

- Elbow Extension
  - Significant mean peak strength differences between suited conditions ($F(2,28) = 4.23$, $p = 0.03$)
    - Suited Un-Pressurized > Suited Pressurized ($p = 0.03$)
  - No practical differences were noted



Results – Strength Assessment

T-Test

- Unsuited
  - Abd < Add (p < 0.01)
  - Flx > Ext (p < 0.01)
- Suited Un-Pressurized
  - Abd < Add (p < 0.01)
  - Flx = Ext (p = 0.55)
- Suited Pressurized
  - Abd < Add (p < 0.01)
  - Flx < Ext (p < 0.01)

Ratio

- Unsuited
  - Abd-Add: 122:191
  - Flx-Ext: 53:49
- Suited Un-Pressurized
  - Abd-Add: 25:43
  - Flx-Ext: 118:112
- Suited Pressurized
  - Abd-Add: 22:41
  - Flx-Ext: 78:90

Discussion – Joint Resistance

- Greater soft goods resistance with shoulder abduction and elbow flexion.
  - Air volume displacement
  - Folding/Compression of soft goods materials
- Lower resistance with shoulder adduction and elbow extension
  - Arm assembly returning to neutral posture
- IMPACT
  - Astronauts must exert more force to work against the pressurized EMU while executing certain arm movements

Discussion – Strength Assessment

- Shoulder Strength
  - Consistent trend of decreasing shoulder strength as subjects progressed through conditions
    - Consistent with previous findings
  - Strength is reduced with pressurized EMU
- Elbow Strength
  - Suited Pressurized strength lower than Unsuited
    - Consistent with previous findings
  - Increased flexion and extension strength from Unsuited to Suited Un-Pressurized
    - Possible that subjects are using the donning stand to brace themselves, giving mechanical advantage

Conclusion

- It is generally accepted that wearing a pressurized EMU reduces the total strength capabilities and mobility performance of the user
  - This investigation indicates that some of these deficits may be due to soft goods resistance
- Strength is augmented by the type of suit support method utilized

Limitations

- Suit Stiffness
  - Suit was unmanned, did not include helmet or lower components
    - Air volume displacement characteristics may not be representative to that of a manned suit
- Strength Assessment
  - Mixed posture
    - Seated unsuited condition, standing in donning stand for suited conditions
  - Low number of test subjects
  - EMG evidence suggests some subjects may not have exerted maximal effort on all strength trials

Future Work

- Soft Goods
  - Should future suits be designed with a different neutral posture?
    - Model the impact of different neutral postures on strength
- Strength Assessment
  - Suit support condition likely affects strength and possibly other functional measures
    - Investigate strength utilizing various available suit support methods