**Introduction**

Extravehicular activity (EVA) is a critical and complex aspect of human spaceflight missions. Astronauts undergo extensive training in the Neutral Buoyancy Lab (NBL), involving many hours of performing repetitive motions at various orientations inside the pressurized space suit. The current U.S. space suit—the Extravehicular Mobility Unit (EMU)—limits human mobility, causes discomfort, and leads to a variety of contact and strain injuries. We focus on two particular areas of injury: the knee and the shoulder.

Limb injuries, such as to the knee, can be caused by rubbing against the soft goods or high muscle forces of the joint. Shoulder injuries are mainly attributed to the EMU's hard upper torso (HUT). While suit related injuries have been observed for many years and some basic countermeasures have been implemented, there is still a lack of understanding of how humans move within the space suit.

The objective of this research is to gain a greater understanding of human-space suit interaction by 1) using a new musculoskeletal modeling framework and 2) performing statistical analysis to relate anthropometry, spacesuit components, and training time to shoulder injury.

**Musculoskeletal Modeling**

**Overview**

A new musculoskeletal modeling framework is developed in OpenSim (Stanford, CA) to quantify musculoskeletal performance of astronauts during EVA and to assess their susceptibility to injury. Analysis is performed on the EMU and on NASA's Mark III spacesuit, designed for enhanced mobility.

**Methods**

Modeling Steps:
1. Human modeling using OpenSim
2. Spacesuit modeling
   - EMU: Space Suit Robot Tester
   - MKIII: Modified fish scale method
3. Human-spacesuit interaction modeling to compute representative human performance measures

**Results**

Knee Flexors Peak Forces (N)

<table>
<thead>
<tr>
<th>Flexor Muscles</th>
<th>Unsuited</th>
<th>EMU</th>
<th>MKIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biceps femoris long head (BLF)</td>
<td>1314±57</td>
<td>1448±33</td>
<td>1428±90</td>
</tr>
<tr>
<td>Biceps femoris short head (BSF)</td>
<td>673±20</td>
<td>669±24</td>
<td>674±19</td>
</tr>
<tr>
<td>Gracilis (GR)</td>
<td>135±6</td>
<td>147±2</td>
<td>145±4</td>
</tr>
<tr>
<td>gastrocnemius medialis (GM) &amp; SF</td>
<td>105±25</td>
<td>296±33</td>
<td>175±24</td>
</tr>
<tr>
<td>Sartorius (SR)</td>
<td>134±23</td>
<td>153±23</td>
<td>153±3</td>
</tr>
</tbody>
</table>

**Discussion & Future Work**

Our musculoskeletal model can be used to assess the potential for knee muscle damage. In the future, we could apply these methods to other joints and other spacesuits. The resulting torque limits could be imposed on future suit designs to decrease the chance of injury.

A similar statistical analysis was performed on subjects whose injury pathologies began in active duty. Future work will involve cross-validation of the model coefficients and tuning of the cut-off parameter. Due to the small sample size, bootstrap and resampling techniques will be used.

Overall, we can use these models to make generalizations about suit fit and training conditions. Eventually, we would like to create an injury susceptibility tool that takes into account all possible mechanisms of injury and weights them to assess muscle injury during EVA, therefore allowing us to determine the feasibility of individual EVA tasks.

**References**