INTRODUCTION
When people with a leg amputation walk on level ground using a powered ankle-foot prosthesis, their metabolic demands are equivalent to those of non-amputees over a wide range of speeds (Herr and Grabowski, 2012). However, the metabolic demands incurred when using this powered prosthesis to walk up and down slopes are not known. Further, it is not clear if a powered prosthesis tuned for level-ground walking can accommodate sloped walking.

Thus, we measured and compared the biomechanics and metabolic demands of using a powered prosthesis (BiOM Inc.) to walk uphill and downhill with two tuning strategies; the optimal level-ground tuning (LVL) and adjusted tuning for each slope (ADJ). We hypothesized that the ADJ would result in a lower metabolic demand compared to LVL at all slopes.

METHOD
Subjects: We recruited three males with a unilateral transtibial amputation and fit each with the BiOM.

Apparatus & Procedures: Subjects walked 1.25 m/s on a dual-belt, force-treadmill at 7 slopes (0°, ±3°, ±6°, and ±9°). We measured lower body kinematics and optimized the BiOM tuning for level ground and at each slope by iteratively changing tuning parameters until prosthetic ankle joint biomechanics matched those of non-amputees (NA) within 1 SD (Auyang and Grabowski, 2013). On two consecutive days, we measured metabolic rates via indirect calorimetry for five minutes during standing and walking at each slope for LVL and ADJ with a randomized trial order.

Data Analyses: We calculated ankle joint moment, power, and work using inverse dynamics (Visual 3D; Matlab). We calculated net metabolic cost of transport (COT) using a standard equation and subtracting standing from walking COT. We used one-tailed t-tests to compare tuning strategies and set significance at p<0.05.

RESULTS
Prosthetic ankle net work for ADJ were within one standard deviation of non-amputee values (Auyang and Grabowski 2013) at ±3° and ±6° and were 21-647% different than LVL values (Table 1).

There were no statistical differences in COT between tuning strategies at any of the slopes (Fig. 1).

DISCUSSION
We tuned the BiOM to match the net ankle work of non-amputees and were able to come within 1 SD at ±3° and ±6°. Though there were large differences in biomechanics there were no differences in COT between ADJ and LVL, which refutes our hypothesis. It is possible that the design of the BiOM limits the ability to match biological ankle biomechanics and metabolic costs when walking ±9°. We intend to conduct future studies to further understand the effects of walking up and down slopes with powered prostheses on people with a leg amputation.

Table 1: Differences in ankle biomechanics between ADJ and LVL [(ADJ-LVL)/LVL*100%]. Range of motion (ROM).

<table>
<thead>
<tr>
<th>Slope</th>
<th>ROM</th>
<th>Peak Moment</th>
<th>Peak Power</th>
<th>Net Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>-9</td>
<td>8.5%</td>
<td>7.3%</td>
<td>-9.2%</td>
<td>-381.4%</td>
</tr>
<tr>
<td>-6</td>
<td>-1.5%</td>
<td>0.2%</td>
<td>22.3%</td>
<td>-109.4%</td>
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<td>5.6%</td>
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</tr>
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<tr>
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<td>9.7%</td>
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<tr>
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<td>8.2%</td>
<td>29.9%</td>
<td>235.9%</td>
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</table>

CONCLUSION
Tuning the BiOM for different slopes resulted in dramatically different biomechanics compared to tuning for level ground, yet there were no differences in metabolic COT between tuning strategies.

CLINICAL APPLICATIONS
Our results provide important information for the prescription of powered leg prostheses. The tuning and control of a powered prosthesis is necessary for normalizing the biomechanics of people with a unilateral transtibial amputation.

Fig 1: Net cost of transport (COT) for subjects walking at 1.25 m/s. Non-amputee data from (Auyang and Grabowski, 2013). *At +6° n=2, at +9° n=1.

REFERENCES
Auyang, A. & Grabowski, A. M. American Society of Biomechanics, Omaha, NE, 2013.