INTRODUCTION
Musculoskeletal simulation enables efficient analysis of the potential impacts of ankle foot orthoses (AFOs) on metabolic power and muscle demand during gait. Simulating gait with AFOs has been used to inform device design by evaluating gait in unimpaired individuals and those with cerebral palsy (CP) [1]. For clinical cases where motion analysis is used to inform treatment selection, simulation methods may improve AFO prescription. However, understanding the impacts of simulation methods on outcomes and recommendations is important for clinical translation.

Musculoskeletal modeling paradigms typically scale a generic model to an individual’s measurements. For example, muscles’ maximum isometric force (strength) is typically scaled based by adjusting population averages by measures such as body-weight or height. Muscle strength in CP is highly variable, rendering population-based strength estimates prone to large errors [2]. Such errors may impact muscle recruitment in gait simulations. However, the extent to which inaccurate muscle strength estimates influence the outcomes of simulation studies is unknown. This study investigated the impacts of altered muscle strength on the predicted changes in muscle demand when walking with and without powered AFOs. We hypothesized that the strength of individual ankle plantarflexor muscles would have the largest impact on predicted changes in muscle demand with AFOs.

METHODS
For eight children with CP and crouch gait (age: 10.5 ± 2.0 years, mass: 34.3 ± 18.9 kg, height: 1.4 ± 0.2 m), we scaled a generic model with 92 musculotendon actuators and 19 degree-of-freedom in OpenSim based on each participant’s skeletal geometry. We scaled muscle strength by height-squared for each participant [3]. We modeled bilateral powered AFOs as sagittal-plane torque actuators with optimal torques large enough that AFOs had negligible influence on the optimization cost function.

To evaluate the interaction between muscle strength and the potential impact of AFOs, we simulated walking with and without AFOs at multiple levels of muscle strength. We reduced muscle strength in all muscles uniformly, in functional groups (e.g., ankle plantarflexors), or in individual muscles. Muscle strength was reduced from the scaled model’s strength (100%) to the point where maximum reserve actuator torques at any joint exceeded 5% of the peak joint moment. The individual muscles analyzed were the gastrocnemius (GAS), soleus (SOL), tibialis anterior (TA), rectus femoris (RF), vasti (VAS), hamstrings (HAMS), gluteus maximus (GMAX), and iliopsoas (ILIO).

To quantify the effect of muscle strength on changes in muscle demand, we computed the slopes of the linear least-squares curve fits of muscle demand during unassisted walking ($m_1$) and walking with AFOs ($m_2$) across strength levels. The slopes were normalized by the average unassisted muscle demand at 100% strength. The difference in slopes, $\Delta = m_1 - m_2$, described the sensitivity of changes in muscle demand with AFOs to strength estimates. We considered $\Delta$’s noteworthy if a 20% change in muscle strength imparted a 5% change in average muscle demand ($|\Delta| > 0.25$) [2, 4].

RESULTS AND DISCUSSION
Predicted reductions in GAS force with an AFO were most sensitive (largest $|\Delta|$) to changes in the strength of all muscles ($-0.3 ± 0.6$), the ankle plantarflexors ($-1.2 ± 0.8$), and individual muscles (GAS: $0.84 ± 0.25$, SOL: $-5.2 ± 2.2$) (Figure 1). This implies that reasonable overestimates of plantarflexor strength in CP may result in clinically-important underestimates of AFO impacts on GAS demand [2]. The SOL was also sensitive to strength estimates, but to a lesser extent and in the opposite direction of the GAS. Knee extensor strength also influenced GAS demand, suggesting that crouch gait, which puts large stress on the VAS, may influence the sensitivity of GAS demand with AFOs [5]. Predictions of AFOs’ impacts on other muscles were less sensitive to overall and functional muscle group strength.

CONCLUSIONS
Muscle strength estimates may have clinically-important impacts on simulated predictions of muscle demand during walking with AFOs. Studies using musculoskeletal simulation to inform medical interventions should justify and test assumptions about muscle strength, particularly in heterogeneous populations like CP.

REFERENCES

ACKNOWLEDGEMENTS
This study was supported by the NSF CBET-14526 and the NIH NCATS TL1 TR000422.