INTRODUCTION
Functional electrical stimulation (FES) has the capacity to alter muscle function when used as a tool for gait retraining in post-stroke individuals. Typically, FES is applied to the ankle dorsiflexors (DF) during the swing phase of gait. More recently, the use of FES has been extended to the ankle plantarflexors (PF) during pre-swing to increase pushoff forces. A goal of the FES gait retraining program tested in the current study was to improve pushoff forces during pre-swing and foot clearance during swing, two common deficits in post-stroke gait, by delivering FES to ankle plantar- and dorsiflexors, respectively. Computer simulation studies can demonstrate the function of individual muscles in healthy and post-stroke gait. Identifying the functions of specific muscles during the gait cycle can be a useful method to assess and enhance gait retraining tools such as FES. Comparison of pre- versus post-training simulations can provide insights into the mechanisms by which gait retraining produces improvements in post-stroke gait function. Additionally, we posit that correlation between simulation results and clinical outcomes can provide validation for the accuracy of simulations as a predictive tool. The objective of this study is to use subject-specific simulations to determine the changes in activation of the ankle plantar and dorsiflexor muscles in stroke patients after an FES gait retraining program.

METHODS
Eight subjects (age 63±8.6, 3 men, >6 months post-stroke) were recruited to participate in a 12-week FES gait retraining intervention, involving both plantar and dorsiflexor stimulation. All subjects signed informed consent forms approved by the Human Subjects Review Board at the University of Delaware. Self-selected speed walking data were collected on an instrumented split belt treadmill (Bertec Corp.) using an 8-camera Motion Analysis system pre- and post-intervention. Three-dimensional, forward dynamic simulations were created from walking trials using OpenSim. The muscle activations and forces required to reproduce the experimentally measured gait kinetics and kinematics were computed using the Computed Muscle Control algorithm.

RESULTS AND DISCUSSION
Two simulations per subjects (16 total) were built from the trials at self-selected speed at the time of collection. Average post-intervention self-selected speed was 0.15 m/s faster than pre-intervention. Soleus muscle activation for a single subject is shown in Figure 1. For this subject, a clear increase in peak activation during double support can be seen post-intervention. During the rest of the gait cycle, there is decreased activation of the soleus post-intervention. This new post-intervention muscle activation pattern is consistent with the timing of PF FES used during the intervention, which stimulated PFs only during pre-swing.

Averaged data for all 8 subjects was calculated for all four muscles during the gait phase of interest, i.e. during double support for the PFs and during swing phase for TA (Figure 2). Although there was an average increase in the total activation during the
gait phase of interest, this change is not significant, potentially due to innate variability between stroke subjects and a limited sample size. Soleus experienced the largest average change across subjects, at 7.8%, followed by 4.58%, 4.45% and 2.56% in the medial gastrocnemius, tibialis posterior, and tibialis anterior muscles, respectively. These average changes correspond to the application of FES during training. Although a trend of an average increase in activation was seen in the three PF muscles during double support (16.82% total increase), only a small average change was seen for these muscles over the full gait cycle (1.3% total). This suggests a change in the PF control pattern across the entire gait cycle, not just during the period of FES application.

Peak knee flexion during swing is hypothesized to increase with increases in PF activation during preswing as a result of greater forward propulsive forces. Although no relationship was found between propulsive forces and changes in activation, those subjects who exhibited the greatest increases in knee flexion also had the largest percent increase in PF activation (Figure 3). This is noteworthy, as it demonstrates a correlation between model predictions and a clinically relevant gait variable measured pre- and post-intervention.

CONCLUSIONS
Notable differences can be seen in the control pattern used by stroke subjects as a response to FES intervention. Evidence of an improved control strategy during gait was seen in the activation of the PF muscles and is consistent with kinematic measures of gait performance. For the first time, muscle-actuated simulations were used to detect the effect of a gait retraining intervention on post-stroke muscle activation patterns.

REFERENCES

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