INTRODUCTION
Contracture and spasticity are common muscle impairments of individuals with cerebral palsy (CP) and contribute to pathologic gait patterns by limiting musculotendon operating lengths and velocities. Musculotendon operating length is the distance of a muscle’s path from origin to insertion, which can be estimated from musculoskeletal modeling. Stretching pathologic muscles has been advocated as a rehabilitation method to reduce the impacts of contracture and spasticity [1]. Ankle foot orthoses (AFOs) are commonly prescribed to individuals with CP to help improve mobility. Adjusting the stiffness of AFOs is also thought to impact the musculotendon length of key muscles, such as the gastrocnemius, and may help to stretch muscles. Ambulation with stretching may provide better ways to integrate rehabilitation exercises into daily living. The aim of this study was to evaluate how musculotendon lengths change with different AFOs in individuals with CP.

METHODS
Motion analyses were performed for 6 children with CP in gross motor function classification system (GMFCS) level I (mean age 7.9 years; range 5.6-12.3 years). The study population consisted of children diagnosed with diplegia (subject 1, 5) and hemiplegia (subject 2, 3, 4, 6). The subjects walked at their self-selected speeds while, 1) barefoot, 2) wearing an Ultraflex AFO with adjustable stiffness, and 3) wearing a Cascade AFO with fixed stiffness. They had 4 weeks of walking experience with each AFO prior to testing. The Ultraflex AFO resists sagittal-plane ankle motion with an elastic polymer at the ankle joint whose stiffness can be adjusted. The stiffness and wedge angles of the Ultraflex AFOs were adjusted by a certified orthotist. Using the motion analysis data, a musculoskeletal model of the lower-extremities [2] was scaled to the subject using OpenSim. For each condition, the subject’s joint angles were determined using inverse kinematics and musculotendon operating length of the gastrocnemius was evaluated as the distance of the muscle path from origin to insertion during the gait cycle. Maximum gastrocnemius length during stance phase was compared with maximum gastrocnemius length from clinical exam, measured as maximum passive dorsiflexion with the knee extended. Kinematics and musculotendon lengths were compared to a group of unimpaired subjects walking at a slow speed, similar to the CP children [3].

RESULTS AND DISCUSSION
The Ultraflex and Cascade AFOs (see green and blue bars, Figure 1A) stretched gastrocnemius length compared to walking barefoot. However, there was significant inter-subjective variability. For example, subjects 4 and 6 had shorter gastrocnemius operating length with both AFOs compared to walking barefoot. Also, both AFOs increased knee extension angle during stance in all except subject 5. Subject 5 had a more flexed knee angle with the Ultraflex AFO compared to walking barefoot and Cascade AFO. Notably, subject 3 presented with knee joint angle hyperextension in barefoot walking and the Ultraflex AFO increased the amount of hyperextension over barefoot walking and the Cascade AFO.

CONCLUSIONS
These results indicate that AFOs can alter the operating length of muscles such as the gastrocnemius and alter joint kinematics. Both Cascade and Ultraflex AFOs increased operating length of the gastrocnemius compared to walking barefoot which may help to stretch the muscle and prevent contracture. Musculoskeletal modeling can be used to evaluate muscle-specific response to AFO designs and assist in orthotic design and rehabilitation in the future. Future studies will need to determine the balance between adjusting orthotic properties to improve gait versus rehabilitation goals such as stretching.

REFERENCES