EMPIRICAL EVALUATION OF SOLEUS AND GASTROCNEMIUS FUNCTION DURING WALKING: IMPLICATIONS FOR EQUINUS GAIT

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INTRODUCTION

Equinus gait, or toe walking, is one of the most common gait abnormalities in children with cerebral palsy. Equinus is often associated with spasticity and/or contracture of the plantarflexors. Surgical treatment can involve Achilles tendon lengthening (lengthens gastrocnemius and soleus) or gastrocnemius recession, depending on the relative involvement of the two muscles. However, distinguishing between dynamic and static equinus in individual plantarflexors remains clinically challenging. Perry suggested that overactivity of the soleus in swing phase should be an indication for Achilles lengthening [1]. Also, Svehlik found that children with dynamic equinus plantarflexed early during stance, whereas children with fixed equinus did not [2]. Hence, delineating the contribution of the soleus and gastrocnemius to stance phase limb motion could help one distinguish which muscle is contributing to the dynamic equinus.

Prior studies have investigated gastrocnemius and soleus function during walking. A modeling study concluded that function of the muscles is unique and changes throughout stance, with the gastrocnemius initiating swing limb motion and the soleus being more responsible for propulsion during pre-swing [3]. A recent electrical stimulation study found that the two muscles induce opposing motion at the knee and ankle during mid-stance, with the gastrocnemius non-intuitively inducing ankle dorsiflexion. However, this prior study did not tightly control muscle stimulation, making it challenging to assess the changing roles of muscles throughout stance. Therefore, the purpose of this study was to directly measure limb motion induced by the gastrocnemius and soleus when stimulated at distinct periods during the stance phase of gait. We tested the hypothesis that early gastrocnemius activity would induce limb flexion, whereas early soleus activity would induce limb extension.

METHODS

Seven subjects (22.9 ± 1.6 yrs, 68 ± 12 kg, 1.68 ± 0.09 m) provided informed consent and participated in the study. Stimulating and recording surface electrodes were placed over the mid-muscle belly of the medial gastrocnemius and lateral soleus. Subjects were instructed to walk at a self-selected pace (1.10 ± 0.10 m/s) on a split-belt instrumented treadmill (Bertec, Columbus, OH) (Fig.1). Ground reaction forces (GRF) were monitored in real time and used to stimulate either the gastrocnemius or soleus at 20% or 30% of a random (on average every 10th stride) gait cycle. The stimulation consisted of 4 current-controlled pulses delivered over 90 ms. Whole-body kinematics were recorded using an 8 camera motion capture system (Motion Analysis, Santa Rosa CA). Inverse kinematics were then used to calculate lower extremity joint angles. Nominal joint angle trajectories were generated for each subject by ensemble averaging across non-stimulated strides. Induced motion was defined as the change in joint angles (relative to the nominal values) observed immediately after the stimulation was introduced. Repeated measures ANOVA was used to assess the effect of stimulation and measurement time on the induced sagittal hip, knee and ankle angles at 50 ms intervals after stimulation onset. Post-hoc analyses (Tukey's) were performed to assess when induced motion was first observed.

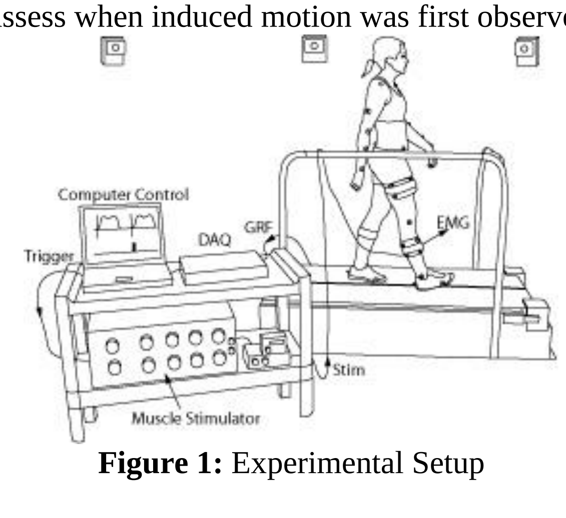

Figure 1: Experimental Setup

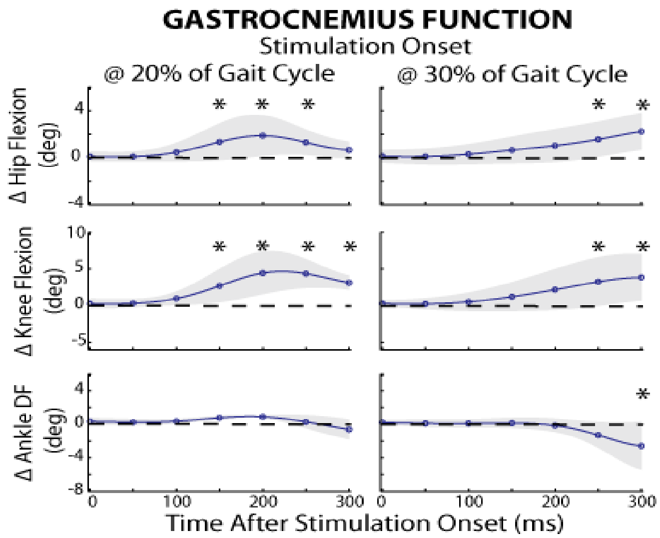

Figure 2: Changes in hip, knee, and ankle angles induced by gastrocnemius stimulation (*p<0.05).

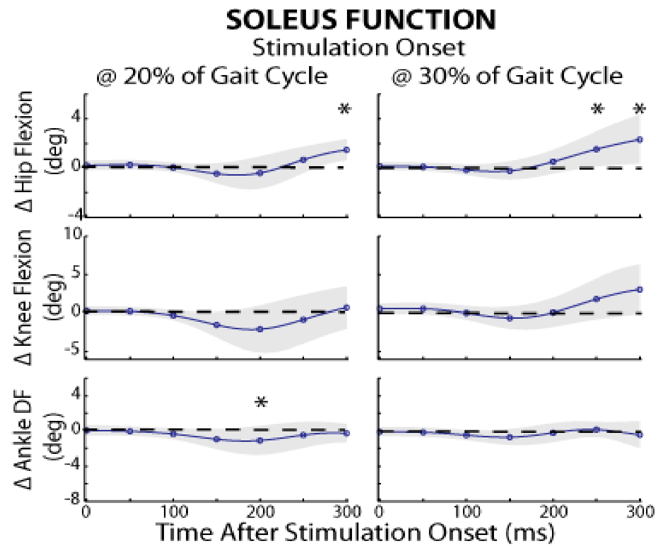

Figure 3: Changes in hip, knee, and ankle angles induced by soleus stimulation (*p<0.05).

RESULTS AND DISCUSSION

Gastrocnemius (Fig.2): The gastrocnemius induced hip flexion and knee flexion when stimulated at 20% or 30% of the gait cycle. The gastrocnemius did not alter the ankle angle when stimulated early, though there was trend toward dorsiflexion. Gastrocnemius stimulation at 30% of the gait cycle induced late ankle plantarflexion.

Soleus (Fig. 3): There was a strong tendency toward the soleus inducing hip and knee extension in response to early stimulation, though the effect was not significant. Early soleus stimulation did induce a significant shift toward ankle plantarflexion. Stimulation of the soleus at 30% of the gait cycle induced significant hip flexion and a tendency toward knee flexion, though these effects were seen substantially later.

Our results show distinct roles of the gastrocnemius and soleus during the stance phase of gait. Consistent with our hypothesis, early gastrocnemius activity did induce hip and knee flexion. While there was no significant effect at the ankle, there was a tendency toward the gastrocnemius inducing ankle dorsiflexion as has been reported previously [3]. In contrast, early soleus activity induced ankle plantarflexion and a strong trend toward early hip and knee extension. These latter results may become significant as we add subject numbers. We note that the induced motions due to early stimulation were all seen within 150-200 ms after stimulation onset, likely reflecting the direct results of induced muscle forces. In contrast, the motion induced in response to later stimulation (30% gait cycle) resulted in significant changes in motion much later, at ~250-300 ms after onset. This would correspond to the pre- and early-swing phases of gait, and could reflect the stimulation inducing an earlier toe-off.

CONCLUSION

We conclude that the gastrocnemius and soleus induce opposing motion at the hip, knee, and ankle during the stance phase of normal gait. The observations support the idea [1,2] that early ankle plantarflexion in stance, i.e. dynamic equinus, may indicate involvement of the soleus.

REFERENCES

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