Compensatory Muscle Activation Patterns of Lower Limb Muscles During Walking

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Summary

Despite low variability in joint angles, lower limb muscle activation measured by surface electromyography (sEMG) shows high stride-to-stride variability. To understand this discrepancy, we analyzed the relationship between activation of the soleus and gastrocnemius muscles across the gait cycle. All subjects showed a negative correlation between the two muscles during terminal stance and pre-swing. This suggests a compensatory mechanism, where a decrease in gastrocnemius activation is accompanied by an increase in soleus activation, allowing the maintenance of consistent kinematics despite variability in muscle activation.

Introduction

Individuals possess unique patterns of walking. However, unique gait patterns are not always constant. While walking, joint angle variability remains low (< 2°) [1]. Conversely, lower limb muscle activation measured by sEMG shows high variability (Coefficient of variation: 31-62%) [2], indicating that similar gait kinematics do not necessarily result in consistent muscle activation patterns. Motor redundancy has been reported as a potential explanation for this variability [3]. Despite existing research, limited studies have investigated how variations in the activation of one muscle influence those of others, particularly in the context of stride-to-stride variability. This study proposes that the ability to sustain consistent kinematics despite variability in muscle activation can be attributed to interactions among muscle activations. The aim of this study is to investigate whether compensatory mechanisms among muscles are observed across multiple subjects. Specifically, we hypothesize that within a muscle group with similar functions, a decrease in the activation of one muscle will be accompanied by an increase in the activation of another.

Methods

IRB approval and informed consents were obtained prior to testing. Ten male participants (age: 25.1 ± 1.10, weight: 65.6 ± 6.11 kg, and height: 1.74 ± 0.02 m) walked on a treadmill for five minutes at a consistent speed. Muscle activation signals for the soleus and gastrocnemius were recorded using sEMG sensors, then rectified and normalized to each participant's Maximum Voluntary Contraction (MVC). These signals were time-normalized to 100 data points. On average, 261 gait cycles were recorded per subject. To investigate potential compensatory mechanisms, Pearson's correlation coefficient was calculated, with statistical significance set at $p < 0.05$. Instead of using mean activation values across the entire gait cycle, we divided the cycle into distinct phases: loading response, mid-stance, terminal stance, pre-swing, initial swing, mid-swing, and terminal swing.

Results and Discussion

We obtained Pearson's correlation coefficient for each subject and gait phase for soleus and gastrocnemius (Figure 1). Each subject has a unique coordination between gastrocnemius and soleus activation during walking. However, during terminal stance and pre-swing, all subjects indicated negative correlation between gastrocnemius and soleus muscles. This suggests a compensatory relationship during these phases where a decrease in gastrocnemius activation is accompanied by an increase in soleus activation.

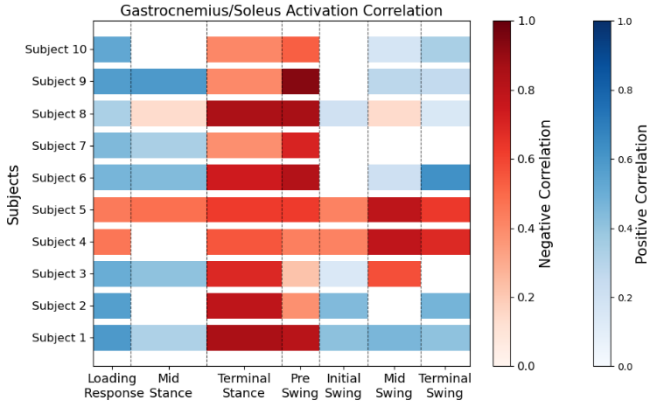

Figure 1: Correlation between gastrocnemius and soleus muscle activation across the gait cycle

Conclusions

This study provides evidence that gastrocnemius and soleus muscles exhibit compensatory activation patterns during walking, particularly in phases of high functional demand, such as terminal stance and pre-swing.

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