Variability of Lower Limb Muscles Activation during Walking in a Large Cohort

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Summary

This study investigated variations in lower limb muscle activation patterns during walking among 120 male participants. Variational autoencoder was used to analyze the muscle activation signal of each individual and trials. Also, lower limb muscle activation timing graph that incorporates variability has been developed through this study.

Introduction

Muscle activation signals provide insights into motor control strategies during human movement. While previous research has documented general patterns of muscle activation during walking [1,2], individual differences exist in these patterns [3]. Although hierarchical clustering methods have been developed to capture the variance of on-off timing of muscle activations [4], this approach typically focuses on activation of single muscles, overlooking the important relationships between different muscle groups. Therefore, this study aims to characterize the variation in lower limb muscle activation patterns during gait in a large cohort. Additionally, we've developed a lower limb muscle activation timing graph that incorporates variability between subjects and across strides.

Methods

Institutional Review Board (IRB) approval and informed consent were obtained prior to testing. A total of 120 male participants (age: 35.4 ± 12.8 years, weight: 74.1 ± 12.5 kg, and height: 173.2 ± 5.6 cm) performed five walking trials, each trial consisting of two steps. Participants walked at their self-selected speed with surface electromyography (sEMG) sensors placed on twelve lower limb muscles. Muscle activation signals measured from sEMG sensors were rectified and normalized based on each subject's maximum voluntary contraction (MVC). The signals were then time-normalized to 100 data points. We trained a variational autoencoder (VAE) to encode muscle activation signals and reduced their dimensionality to a two-dimensional latent space. Muscle activation timing during walking was determined using a threshold-based approach. The threshold was set at 0.383 times the maximum activation (α * maximum activation, where $\alpha = 0.383$). This threshold value was set by minimizing the difference from previously reported on-off muscle timing patterns during walking [2].

Results and Discussion

We obtained continuous distribution of muscle activation patterns in the latent space of the VAE (Figure 1). Four distinct clusters were chosen for analysis. The clusters were characterized by their position along two primary VAE axes: axis 1 (negative: green cluster; positive: blue cluster) and axis 2 (negative: purple cluster; positive: red cluster). The purple cluster demonstrated consistently low activation across all lower limb muscles, while the red cluster showed high activation patterns. The green cluster was characterized by low thigh muscle activation coupled with high shank muscle activation, suggesting a gait strategy that predominantly utilizes the ankle joint. In contrast, the blue cluster exhibited high thigh muscle activation with relatively low shank muscle activation, indicating a knee-dominant walking strategy.

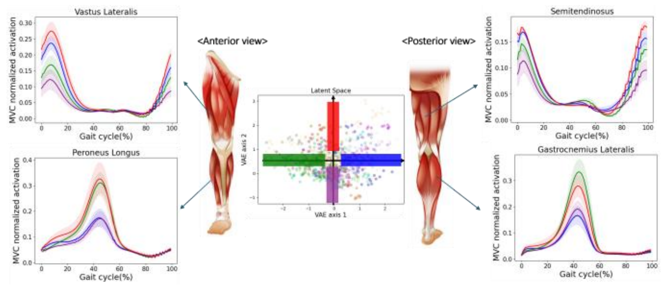

Figure 1: Muscle activation pattern distribution along VAE axis

The observed muscle activation timing patterns were similar to the previously reported generalized on-off timing patterns (Figure 2a). However, substantial variability was observed in both the onset and offset timing across subjects and strides, as illustrated by the error bars (Figure 2b).

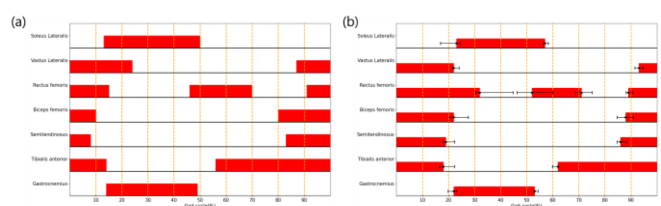

Figure 2: (a) Generalized on-off muscle timing during walking [2] (b) On-off muscle timing of 120 subjects and error bar depicting the variance of on-off timing between subjects and strides

Conclusions

This study characterizes the distribution of lower limb muscle activation patterns during walking and demonstrates intra, inter-subject variability in these patterns. These analyses enhance the understanding of variation in motor control strategies during walking.

Acknowledgments

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References

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