Analyzing Agonist-Antagonist Muscle Coordination in Isometric Contractions Using PCA

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Summary

A stable movement execution relies on the coordination of agonist and antagonist muscles, which play distinct roles in motor control. This study investigates how these muscles function together during isometric contraction and identifies key metrics for muscle function evaluation. Using HD-sEMG and principal component analysis (PCA), we analyzed muscle activation patterns and found that agonist muscles follow structured, force-dependent activation patterns, while antagonist muscles exhibit greater variability. These findings suggest that antagonist muscles employ more flexible control strategies, which may be critical for movement adaptability. This study provides insights into the neuromuscular mechanisms underlying coordinated movement and proposes a framework for assessing muscle function based on both amplitude and frequency-based metrics.

Introduction

The coordinated muscle activity of agonist and antagonist muscles is essential for stable movement execution. Previous studies have reported differences in muscle activity patterns between these muscles [1], suggesting that antagonist muscles fine-tune movement precision in motor control. However, the mechanism by which these muscles regulate movement during coordination remains unclear. This study examines their differences and aims to identify key metrics for muscle function evaluation.

Methods

The subjects performed isometric contractions at a 90-degree elbow joint angle, increasing force by 10% MVC per second until reaching 100% MVC, then decreasing at the same rate. The force output and muscle signals were recorded simultaneously at 2 kHz (frequency range: 15–300 Hz). Muscle activity of the biceps brachii (agonist) and triceps brachii (antagonist) was recorded using a 7×4 HD-sEMG electrode grid (10 mm inter-electrode distance). For analysis, wavelet transformation was applied to the EMG signals for frequency analysis. Afterward, eleven features related to amplitude, frequency, and force output were extracted every 500 ms, including mean MVC, RMS, and instantaneous frequency. These extracted features were then analyzed using PCA to identify dominant patterns in muscle activation. The extracted principal components were analyzed separately for agonist and antagonist muscles to compare coordination strategies.

Results and Discussion

PCA revealed clear differences in muscle activation between agonist and antagonist muscles (Figure 1). In the agonist muscles, PC1 explained 38-47% of the variance, reflecting a structured and force-dependent activation strategy optimized for contraction efficiency. In contrast, PC1 in the antagonist muscles explained 37-55% of the variance, showing greater variability across participants. This suggests that antagonist muscles employ more adaptive control strategies, likely to compensate for movement perturbations and fine-tune stability. Feature loadings showed strong associations between RMS and high-frequency power (120-300 Hz) in agonist muscles, reinforcing their structured activation pattern. Conversely, antagonist muscles were more associated with spectral entropy and instantaneous frequency variability, suggesting greater neuromuscular adaptability and individual differences in control strategies. This variability indicates that antagonist muscle coordination is highly individualized, potentially affecting movement precision and stability across participants.

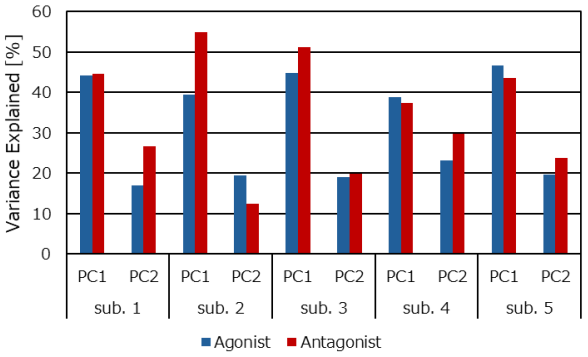

Figure 1: PC1 and PC2 variance explained for agonist and antagonist muscles across all participants.

Conclusions

This study highlights that antagonist muscle coordination strategies vary across individuals, potentially influencing movement precision and stability. The results suggest that muscle function evaluation should incorporate amplitude-based metrics for agonist muscles and frequency-based metrics for antagonist muscles to capture the complexity of neuromuscular coordination. Understanding these differences may provide deeper insights into the mechanisms that govern movement execution and control, helping to clarify how muscle coordination contributes to movement efficiency and stability.

References

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