Forearm muscles' co-contraction patterns during cylindrical grasp: an electromyography-based synergy analysis

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Summary

Synergy analysis was used to identify activations of forearm muscle groups during grasp to explore the consistency of muscle coordination across healthy individuals. Surface electromyography (sEMG) data from seven forearm muscle groups of fourteen participants were processed, and three distinct synergy modules with their activation patterns were extracted, each reflecting unique functional contributions to the grasp. These findings highlight the diverse and specialized contributions of forearm muscles to grasping, providing a robust baseline for future investigations into neuromuscular coordination in pathological conditions.

Introduction

Understanding the coordination of forearm muscles during functional tasks is critical for investigating neuromuscular control strategies, identifying musculoskeletal disorders, guiding rehabilitation, and improving control in hand models and prostheses [1,2]. Synergy analysis provides a valuable approach to unravel muscles activation patterns [2]. Non-negative matrix factorization (NNMF) has proven effective in identifying synergies for functional tasks and comparing healthy vs. pathological conditions [2-4]. However, these studies used invasive intramuscular EMG and analyzed only a few muscle groups for grasp tasks, without focusing on co-contraction patterns. Grasp, as a fundamental hand activity, is an ideal starting point for investigating co-contraction patterns. The aim of this study was to extract muscle synergy patterns during a cylindrical grasp task in healthy individuals and check the consistency of these patterns across them.

Methods

Forearm muscle activation patterns from fourteen healthy women, collected while they performed cylindrical grasp with maximum effort, were analysed [1]. Seven sEMG sensors (Biometrics Ltd., Newport, UK, 1000 Hz) were placed such that they collected signals that represented muscle activity during hand and wrist movements (Figure 1). Signals were filtered using a 4th-order Butterworth band-pass filter using zero-phase filtering, rectified and smoothed by the Gaussian method, and normalized to maximum voluntary contraction (MVC) values of each sensor [1]. The NNMF method was then recruited to extract the synergy modules and their related activation patterns for each participant. Between one and six synergies were extracted and compared to find the most suitable, considering local (for each sensor) and global (for all seven sensors) variance accounted for ($VAF_{local} > 85\%$ and $VAF_{global} > 95\%$) constraints. The extracted synergies were then normalised and their consistency across participants was checked using the unsupervised k-means clustering method.

Results and Discussion

Three synergies were extracted from the sEMG signals of the seven sensors for each participant ($VAF_{global} = 99.62 \pm 0.07\%$, mean-$VAF_{local} = 99.46 \pm 0.35\%$, root-mean-square-error = $3.97 \pm 0.73\%$ MVC, normalized-root-mean-square-error = $7.49 \pm 1.05\%$). The similar synergies across participants were then identified and clustered into three groups (S1-S3, the same number as the synergy modules, Figure 1). S1 focused on wrist flexion, extension, and ulnar-deviation, S2 focused on wrist extension and radial-deviation, and S3 focused on finger flexion and thumb extension, abduction, and adduction.

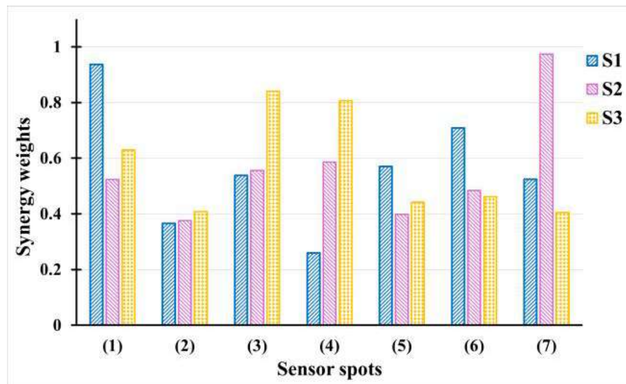

Figure 1: Classified synergy patterns for seven sEMG sensors collecting signals that represented muscle activity during: (1) wrist flexion/ulnar-deviation, (2) wrist flexion/radial-deviation, (3) finger flexion, (4) thumb extension/abduction/adduction, (5) finger extension, (6) wrist extension/ulnar-deviation, and (7) wrist extension/radial-deviation [5].

Conclusions

This study extracted similar muscle synergies across healthy participants during a grasp task, revealing complex distinct coordination strategies among forearm muscles. The baseline synergy patterns established in this study provide a foundation for identifying deviations in muscle coordination associated with pathological conditions, offering valuable insights for both clinical diagnosis and targeted rehabilitation approaches.

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