

REVEALING THE NEURAL BASIS OF MUSCLE SYNERGIES IN HUMANS THROUGH DIRECT ELECTRICAL STIMULATION ON THE CORTEX

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INTRODUCTION

During voluntary movement, the human motor system may generate complex motor commands by translating motor intentions into recruiting a small number of motor output units, called muscle synergies, that co-activate a group of muscles involved in motor behaviors. Muscle synergies decomposed from behavioral electromyographic signals (EMGs) can simplify the control of voluntary behaviors. However, direct neurophysiological evidence for the existence of muscle synergies in humans is still lacking. In this study, we ask whether it is possible to retrieve muscle synergies observed in daily activities by direct electrical stimulation (DES) of focal motor cortical loci during awake craniotomy for patients undergoing glioma resection.

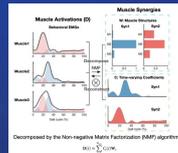


Fig.1 The Muscle-Synergy Model

METHODOLOGY

Patients diagnosed with gliomas while still having normal motor functions (N = 8) were enrolled in two upper-limb experimental sessions — the pre-operation (pre-op) behavioral session with 10 motor tasks and the operation (intra-op) session that applied DES. Multi-muscle surface EMG channels (12 upper-limb muscles) were recorded in both sessions, then behavioral muscle synergies and DES-derived muscle synergies were decomposed from the recorded EMGs by the Non-Negative Matrix Factorization (NMF) algorithm, respectively. The characteristics of the DES-derived and behavioral muscle synergies were compared and evaluated by statistical methods.

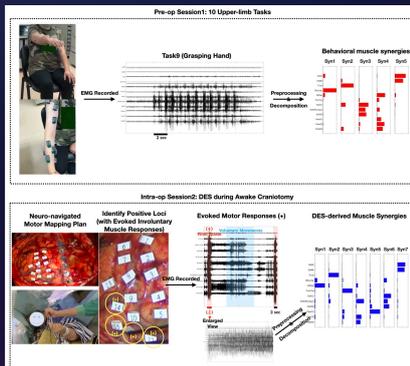


Fig.2 Experimental and Preprocessing Procedures of Session1 and Session2

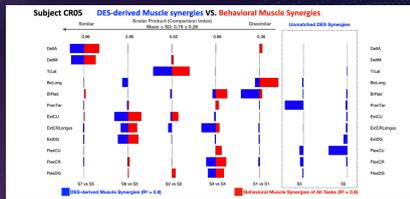


Fig.3 Illustration of Comparing the Synergy Muscle Structures (Pre-op Sessions for Behavioral Synergies; Intra-op Sessions for DES Synergies)

CONCLUSION

We demonstrated that it is possible to access and map out muscle synergies in the primary motor cortex of humans by applying DES to the M1. The neural basis of upper-limb muscle synergies can be revealed by applying DES to the motor cortex of humans. Our results provided direct neurophysiological evidence for the existence of muscle synergies in the CNS of humans. The primary motor cortex should be involved in the recruitment of muscle synergies.

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RESULTS

For 8 subjects, all the DES-derived muscle synergies and behavior muscle synergies can be described by k-means clusters. Compared with the behavioral part, more DES-derived muscle-synergy clusters can be identified. Behavioral cluster centroids could be matched to DES-derived cluster centroids with different levels of similarities.

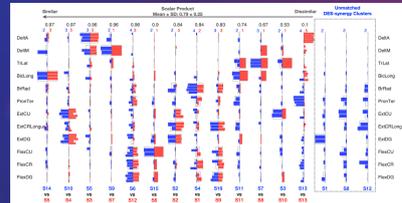


Fig.4 The Clusterable DES-derived and Behavioral Muscle Synergies

Flexible recruitment of the DES-derived muscle synergies, mainly through synergy merging, provided better explanations for the behavioral tasks.

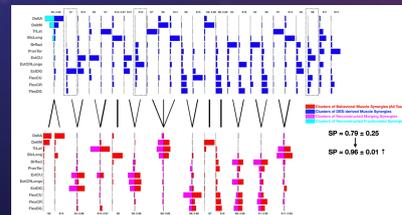


Fig.5 The Merging Trend of DES-derived Muscle Synergies

The individual comparison results suggested that the similarities of DES-derived muscle synergies to behavioral muscle synergies varied across tasks and subjects.

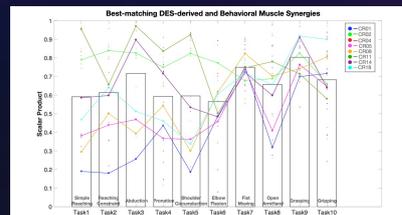


Fig.6 Individual Similarities of DES-derived Synergies to Behavioral Synergies

DISCUSSION

The high similarities (SP > 0.75) of DES-derived muscle synergies to behavioral muscle synergies were obtained from direct comparison and synergy merging. The merging of muscle synergies can be explained at different levels of the motor system.

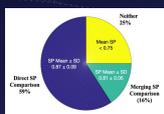


Fig.7 Percentages of Comparison Modes with High Similarities (SP>0.75). Blue Pies: Direct Comparisons; Green Pies: Synergy Merging.

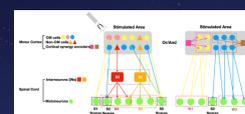


Fig.8 Possible Organizations that explain the Merging of Muscle Synergies.