Dynamic Brain-Muscle Coupling during elbow contraction in Older Adults Using Polynomial Regression Models

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Summary

This study aimed to investigate the dynamic modulation of brain-muscle synergy during elbow flexion tasks at 30% and 70% of maximum voluntary contraction (MVC) in older and younger adults by integrating functional near-infrared spectroscopy (fNIRS) and electromyography (EMG) techniques, utilizing polynomial regression models to analyze nonlinear brain-muscle interactions. A novel Temporal Dynamic Graph Fourier Transform (TDGFT) method was proposed to dynamically analyze brain signals during motor tasks. Sixteen older adults and sixteen younger adults were recruited for the study. The results demonstrate that older adults rely on multi-regional brain coordination for motor control during low-intensity tasks, while reducing cognitive load to enhance motor efficiency during high-intensity tasks. This study revealed age-related neural adaptive changes in motor control, providing new insights into the decline in motor abilities in older adults.

Introduction

Aging impairs motor control, necessitating the study of dynamic brain-muscle coupling to capture time-varying cortical-muscular interactions. Constrained by static frameworks and linear assumptions, traditional methods may fail to address the nonlinear and rapidly evolving dynamics of these interactions [1]. Furthermore, research on the dynamic processes of brain signals faces challenges, such as the inability to adaptively partition dynamic phases and the lack of integrated analysis of structural networks and functional signals [2]. This study integrated fNIRS and EMG to introduce the TDGFT for analyzing dynamic brain signals, alongside polynomial regression models to quantify nonlinear brain-muscle correlations.

Methods

Sixteen elderly and sixteen younger adults performed isometric elbow flexion tasks at 30% and 70% MVC under visual feedback, while fNIRS and EMG data were collected simultaneously to analyze brain-muscle coupling dynamics. The fNIRS signals were analyzed using the TDGFT method, which employed constrained k-means clustering to adaptively partition the underlying dynamic graph structure. Eigenvector centrality was calculated within brain regions to incorporate temporal information into functional activity, followed by graph Fourier transform to derive spectral properties and compute energy values across brain regions during dynamic processes. Polynomial regression models were used to analyze the dynamic coupling relationships between the energy values of different brain regions (e.g., prefrontal cortex, motor cortex, and occipital lobe) and the integrated electromyography (IEMG) values of the biceps brachii during 30% and 70% MVC tasks. Through time-resolved R² curves, the study revealed patterns of brain-muscle synergy under varying task intensities and conditions, highlighting differences in motor control between older and younger adults.

Results and Discussion

The results indicated that during 30%MVC, older adults maintain motor control through multi-regional brain coordination(Fig.1). In contrast, during 70%MVC tasks, older adults reduced cognitive load and enhance motor efficiency to meet task demands, relying more on lower-level motor control regions such as the motor cortex [3]. Younger adults, on the other hand, demonstrated significant control of muscle co-contraction by the motor cortex across both task intensities, reflecting their efficient neuromuscular coordination capabilities(Fig.2).

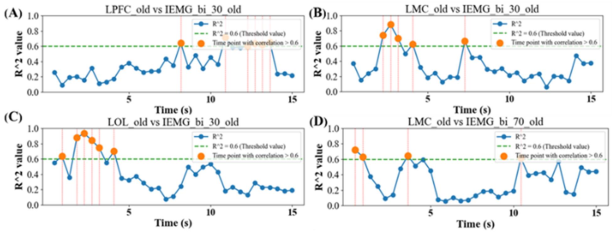

Figure 1: Dynamic coupling changes in older adults.

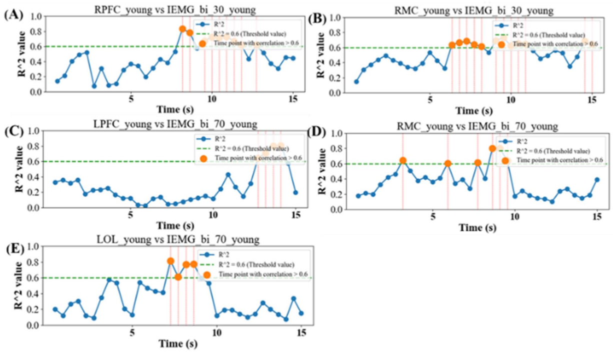

Figure 2: Dynamic coupling changes in young adults.

Conclusions

The findings of this study provided novel insights into the decline in motor control abilities in older adults and offer a theoretical foundation for rehabilitation interventions.

References

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