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Assessing the Relationship between Gesture Intuitiveness and Muscle Network Efficiency: A Comparison of NMF and Intermuscular Coherence Analysis Methods

Eduardo Freire[1,2], Leonardo Cano[1,3], Gonzalo Gerez[1,3], Manuel Parajón[1,3], Ana Albarracín[1], Fernando Farfán[1]
[1]LINTEC/FACET/UNT/INSIBIO/CONICET – San Miguel de Tucumán, Argentina
[2]Electrical Engineering Department, UFS, São Cristóvão, SE, Brazil
[3]FACDEF/UNT - San Miguel de Tucumán, Argentina
Email: efreire@conicet.gov.ar

INTRODUCTION & AIM

Context: Human-machine interaction research is focused on developing more natural and intuitive interfaces using new technologies. Gesture-based interfaces are a key area of interest [1].

Challenge: A critical issue is evaluating whether the gestures are truly intuitive [2]. Traditional methods rely on subjective questionnaires, but neurophysiological indicators could provide a more objective and efficient metric.

Objective: This study tested the hypothesis that improved coordination of muscle synergies could serve as a reliable indicator of gesture intuitiveness.

METHOD

Participant: One healthy 25-year-old left-handed male, with no neurological or muscular disorders, voluntarily participated after providing informed consent.

Procedure: The participant performed seven gestures related to "FOLLOW ME," following instructions given by an experimenter (Fig. 1). Gestures were presented with 5-second intervals, and the series was repeated six times with randomized order and 3-minute breaks between series.

Data Collection: EMG signals from 16 muscles were monitored (Fig. 2). Muscle networks were constructed using Non-Negative Matrix Factorization (NMF) and Intermuscular Coherence (IMC) across distinct frequency bands [3, 4].

Pre-processing: The movement phase was identified from the onset of hand movement until returning to the initial position. EMG signals were filtered using a 5th-order Butterworth filter (13–90 Hz, band stop 49–51 Hz). Intermuscular Coherence (IMC) was computed between all muscle pairs following a five-step process: auto spectrum calculation, cross-correlation, mean auto spectrum, Magnitude-Squared Coherence, and extraction of significant regions. IMC was calculated for 120 comparisons across 16 muscles in three frequency bands: beta (15–29 Hz), gamma1 (31–49 Hz), and gamma2 (51–80 Hz) [5].

Analysis: Muscle networks were analyzed using metrics like Weighted Global Efficiency (WGE) [6] and Effective Average Strength (EAS) [7]. Correlations between these metrics and the Intuitiveness Level (IL) of each gesture were also calculated.

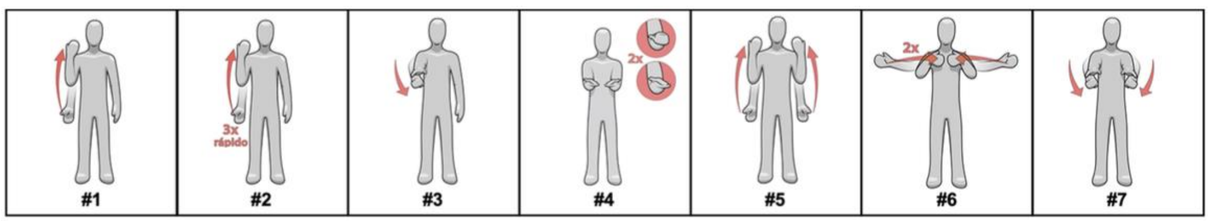

Fig. 1. Schematic representation of the seven gestures performed by the participant.

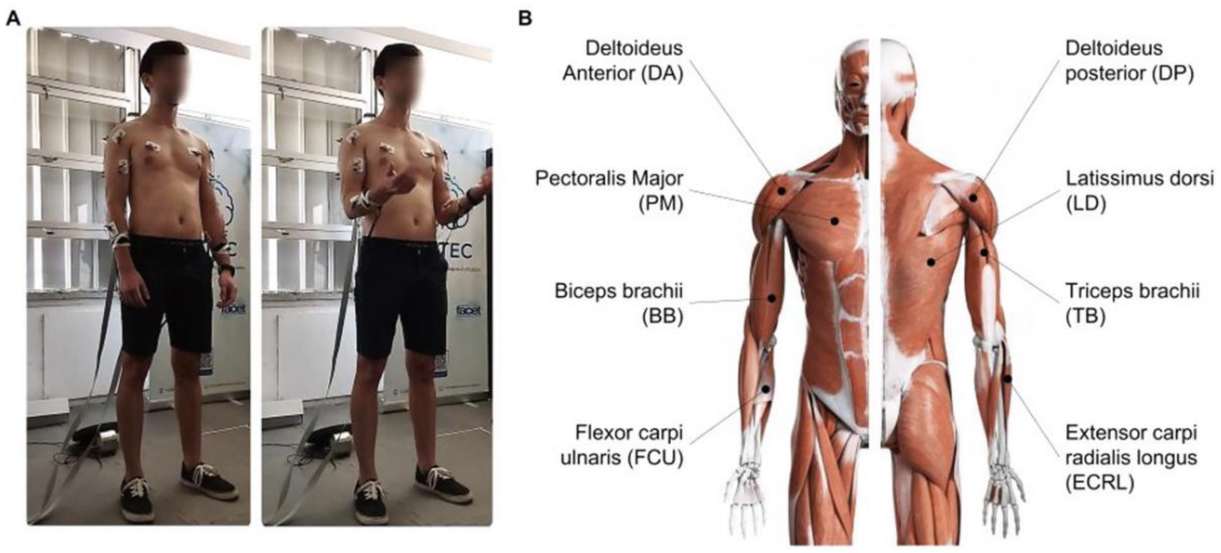

Fig. 2. (A) Experimental setup: on the left, the subject observes the instruction; on the right, the subject performs gesture #4. (B) Schematic layout of muscle sensors on the front and back of the subject's body.

RESULTS & DISCUSSION

Muscle synergy networks exhibit higher connectivity than those derived from Intermuscular Coherence (IMC) (Fig. 3).

Notably, the Weighted Global Efficiency (WGE) and Effective Average Strength (EAS) of synergy-based muscle networks in the Gamma 1 band significantly correlate with Intuitiveness Level (IL), with p-values of 0.10 and 0.05, respectively.

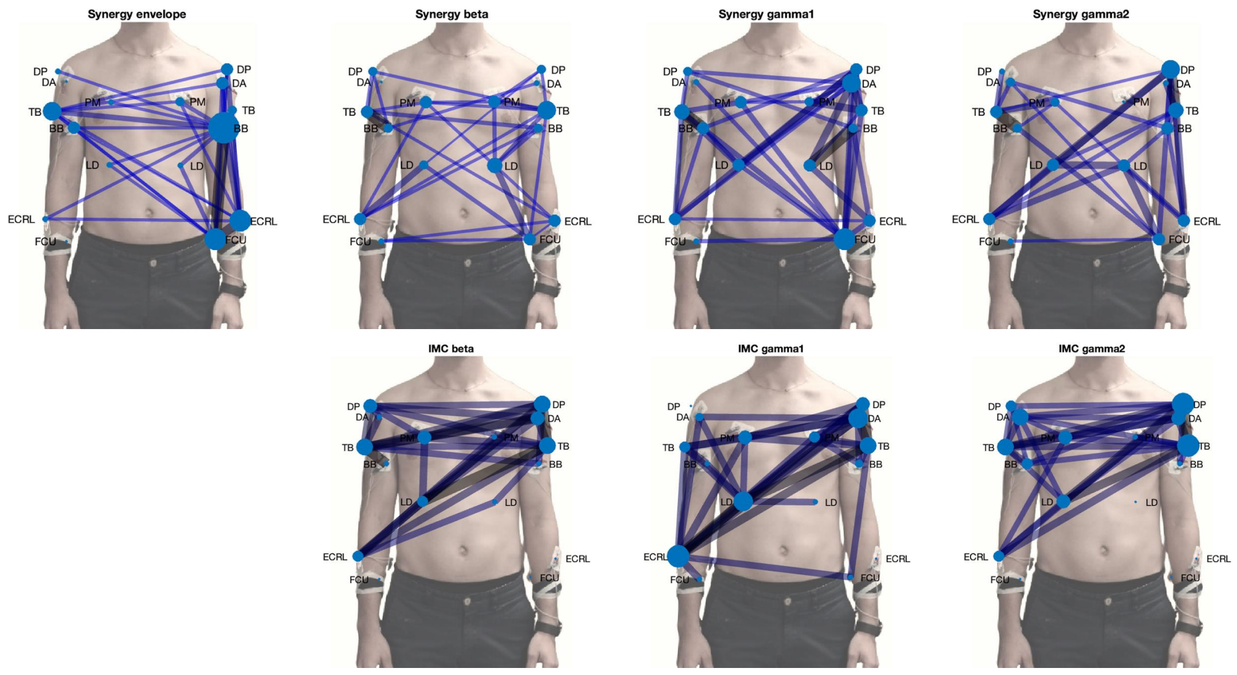

Fig. 3: Example MNs for Gesture #4. The first row shows MNs constructed using NMF from the envelope of the EMG signal in the Beta, Gamma 1, and Gamma 2 frequency bands, respectively. The second row displays MNs constructed using IMC for the same frequency bands: Beta, Gamma 1, and Gamma 2, respectively.

CONCLUSION

The results provide substantial evidence supporting a significant correlation between the intuitiveness level and muscle synergies analyzed using both NMF and IMC approaches.

FUTURE WORK / REFERENCES

Future work: Future work will focus on enhancing the research protocol and expanding the sample size by recruiting additional volunteers.

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