Hybrid neural interfaces and novel ways of assessing corticomuscular coupling

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INTRODUCTION: Corticomuscular coupling is primarily explored by analysing the relationship between electroencephalographic (EEG) and electromyographic (EMG) signals. Different measures of coupling can be utilized, ranging from corticomuscular coherence to Granger causality and transfer entropy. Previous research on corticomuscular coupling focused on both healthy individuals and different groups of patients, including stroke and pathological tremor patients. Findings from studies on healthy subjects indicate that corticomuscular coupling strengthens with muscle exertion (Dal Maso et al., 2017). In particular, beta band (13–30 Hz) coupling intensifies during static force generation, while gamma band (30–80 Hz) coupling is more prominent during dynamic force production (Gwin et al., 2012; Liu et al., 2019). Investigations also reveal variations in coupling levels between acute and chronic stroke patients, with corticomuscular coupling correlating with the efficacy of rehabilitation (von Carlowitz-Ghori et al., 2014).

Assessments of functional coupling can be extended to clusters of motor units identified from skeletal muscles. Motor unit discharge patterns may be estimated by advanced computer algorithms analysing high-density surface electromyograms – HDEMG (Holobar et al. 2007). Research indicates that coherence estimation depends upon the number of identified motor units, with greater numbers revealing significant coherences among pools of motoneurons at frequencies higher than previously noted (Muceli et al., 2022). Whether analogous dependencies on the number of identified motor units exist in corticomuscular coupling remains uncertain.

Recent research by Tanzarella et al. (2021) has highlighted that motor units within the same muscle can organize into distinct functional clusters, which may even extend across different muscles. Traditional EEG-EMG coupling analysis fails to distinguish between these clusters, as all detected motor units indiscriminately contribute to EMG recordings. Consequently, decomposing EMG signals into contributions from individual motor units and grouping them into separate functional clusters could potentially enhance corticomuscular coupling assessment. However, the dependencies of corticomuscular coupling on the functional clustering of motor units remain to be investigated.

METHODS: In the HybridNeuro project (www.hybridneuro.feri.um.si), funded by the European Union's Horizon Europe Research and Innovation Program (HybridNeuro project, GA No. 101079392), we are developing novel biomarkers of corticomuscular coupling. In particular, we are identifying individual or cumulative motor unit discharge patterns from HDEMG recordings and using the identified motor unit discharge patterns to implement and test novel methodologies for assessing corticomuscular coupling.

Up to now, two different methodologies for analysing HDEMG-EEG coupling have been designed. The first one exploits the discharge patterns of individual motor units identified from HDEMG to build a motor unit-specific EEG filter. When applied to EEG recordings, this filter extracts the component that is functionally connected to the motor unit discharge patterns.

The second approach replaces the EMG signals in corticomuscular coupling calculation with the previously introduced motor unit activity index (Holobar et al. 2007). The latter estimates the activity of all the motor units active in the detection volume of HDEMG electrodes, but, similar to motor unit identification, compensates for the negative impacts of motor unit action potentials in the estimation of the corticomuscular coupling. This methodology is fully automatic and extremely fast.

RESULTS: Preliminary results of motor unit-based EEG filters applied to EEG recordings of young healthy population show significantly increased sensitivity of corticomuscular coupling detection compared to the current state-of-the-art techniques. This methodology also supports the analysis of corticomuscular coupling in different functional clusters of motor units and the calculation of topological maps of cortical activity.

The performance of the motor unit activity index is comparable to much more time-consuming approaches that are based on motor unit identification from HDEMG and require significant human operator effort in manual editing the decomposition results. The motor unit activity index identifies a significantly larger number of motor units than HDEMG decomposition. Therefore, it has the potential to increase the sensitivity of corticomuscular coupling detection. However, this methodology does not support the grouping of the identified motor units into functional clusters.

DISCUSSION & CONCLUSIONS: Identification of motor unit behaviour from HDEMG supports novel methodological approaches to the corticomuscular coupling assessment and increases its sensitivity. The clinical potential behind the presented approaches is yet to be assessed in different populations of patients. In the HybridNeuro project, we will test them on a cohort of stroke patients during their rehabilitation. However, these tests can be extended to many other neuromuscular and neurodegenerative disorders.

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REFERENCES:

[1] Dal Maso, Fabien, Marieke Longcamp, Sylvain Cremoux, and David Amarantini. "Effect of training status on beta-range corticomuscular coherence in agonist vs. antagonist muscles during isometric knee contractions." Experimental Brain Research 235 (2017): 3023-3031.

[2] von Carlowitz-Ghori, Katherina, Zubeyir Bayraktaroglu, Friederike U. Hohlefeld, Florian Losch, Gabriel Curio, and Vadim V. Nikulin. "Corticomuscular coherence in acute and chronic stroke." Clinical Neurophysiology 125, no. 6 (2014): 1182-1191.

[3] Gwin, Joseph T., and Daniel P. Ferris. "Beta-and gamma-range human lower limb corticomuscular coherence." Frontiers in human neuroscience 6 (2012): 258.

[4] Holobar, Aleš, and Damjan Zazula. "Multichannel blind source separation using convolution kernel compensation." *IEEE Transactions on Signal Processing* 55, no. 9 (2007): 4487-4496.

[5] Liu, Jinbiao, Yixuan Sheng, and Honghai Liu. "Corticomuscular coherence and its applications: A review." Frontiers in human neuroscience 13 (2019): 100.

[6] Muceli, Silvia, Wigand Poppendieck, Aleš Holobar, Simon Gandevia, David Liebetanz, and Dario Farina. "Blind identification of the spinal cord output in humans with high-density electrode arrays implanted in muscles." Science Advances 8, no. 46 (2022): eabo5040.

[7] Tanzarella, Simone, Silvia Muceli, Marco Santello, and Dario Farina. "Synergistic organization of neural inputs from spinal motor neurons to extrinsic and intrinsic hand muscles." Journal of Neuroscience 41, no. 32 (2021): 6878-6891.