Summary on detecting and decoding spinal motor neuron spike trains for understanding the neural control of movement

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The goal of neuro-rehabilitation is to aid recovery from a nervous system injury in order to minimize and/or compensate for any functional alterations resulting from it. In order to achieve this goal we recover information from the motor units which are composed by motor neuron and muscle fibers. The neural volley from the motor cortex is conveyed to motor neurons within the spinal cord and from there to the muscle fibers that are innervated. The result of the summation of the motor unit action potentials (MUAPs) discharged by the motor neurons in the spinal cord constitute the electromyographic signal (EMG). An EMG signal can be thus modeled and reconstructed as a linear combination of single motor unit spike trains and the MUAPs. EMG signal can be recorded by using both invasive and not-invasive techniques. Intramuscular EMG is a technique used to quantify muscular electrical activity which leverages on the use of invasive electrodes that reaches directly the muscle fibers. Although the signal recorded with this technique is less noisy, it is more selective and thus its application is mostly limited to clinical environment. Surface EMG, on the contrary, is a non-invasive technique. It provides good signal to noise ratio, but it can be influenced by factors such as anatomical, geometrical and physical aspects, detection system, fiber membrane properties and motor unit control properties. It may be recorded using bipolar electrodes or also, using multi-channel sensors (this technique is usually addressed as high density EMG).

Lately, much effort has been put into the issue of the reconstruction of the motor unit spike trains from the HD-EMG. This problem can be modeled as following: called s the vector containing all the motor unit spike trains, and H the vector of all the single motor unit action potentials (MUAPs), we can reconstruct the EMG signal as $x = Hs$. When using the single bipolar recordings the problem shows infinite solution. Thus, both a temporal and spatial resolution is needed in order to extract the information about the motor unit spike trains. Therefore, multi-channel recordings are more suitable for reliable estimation of the motor unit spike trains. In order to decompose a high-desnity EMG signal, the first step to be performed is the extension of

the data matrix. Then, this data are whitened in order to enhance the non-gaussianity of the signals. After that, several iterations are performed in order to obtain the single motor unit pattern. The result is a spiky signal and the spike trains are then estimated by fixing a threshold.

The obtained motor unit spike trains can then be used in different context, ranging from neurophysiology to the characterization of pathologies such as parkinson's disease. For example, HD-EMG has been used to investigate and quantify the neural drive to muscle. Coherence analysis has been applied to motor unit spike trains and the result spectrum is then analyzed according to the different frequency band of interest. It has been demonstrated that the coherence within the frequencies 1-5 Hz reflects the neural drive to muscles, while the content within 8-10 Hz is mainly related to tremor.

In conclusion, the application of high-density EMG and in particular of the information that can be extracted from it (such as motor unit spike trains) is relevant in the field of neuro-rehabilitation. In fact, with this information it is possible to unravel many neuro-physiological mechanisms underlying motor control, investigate and characterize many neurological pathologies and also advance in the field of prosthesis control.