Monitoring and Neuromodulation of Motor Control after Upper Motor Neuron Lesion

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Judicious use of electrophysiological methods of assessment can provide a valuable adjunct to clinical monitoring of neuroplastic changes in motor control after intervention or recovery. Alteration of the upper motor neuron whether from injury or disease results in a wide variety of motor dysfunction with distinctively different features from those arising from lower motor neuron lesions. Successful development of interventions depends on accurate and adequate assessment of motor function. This paper reviews electromyographic methods to carry out such assessments, examples of such use after spinal cord injury and stroke, and reviews neurophysiological evidence of changes in stroke after mesh glove interventions.

Although challenging for routine clinical use, the most direct measure of motor control would be to monitor the activity of the spinal motor neurons. However, surface electromyography or recording of the electrical activity arising from the muscles and driven by those motor neurons is a practical way of gaining insights into the activity of the motor control of nervous system as the basis for functional assessment of neurocontrol of movement, in other words functional EMG (fEMG) In the case of fEMG, emphasis is placed on broad representation of motor activity, rather than on the selectivity of motor units recorded; thus, surface electrodes are used to detect the activity to be monitored.

The characteristics of the surface EMG signal are determined by the biophysics of the recording situation, determined predominantly by the amount of tissue depolarized (a function of both the size of the muscle and the imposed firing rate), and 2) the distance from the muscle to the recording electrode. Thus, the depth of the muscle beneath the skin, and placement of the electrode on the skin are major determinants in establishing the amplitude and frequency characteristics of the signal. The surface electromyographic (sEMG) signal can therefore be considered to represent the summation of activity or pooled firing rate (PFR), of the muscle recorded, an indication of the strength of activation of that one muscle.
Given that muscles do not act in isolation, and considering that the elementary functional units of living things are synergies, which is a functional grouping of structural elements together temporarily constrained to act as a single coherent unit, the information from just one muscle group is insufficient to characterize motor control. Rather, it is necessary to document the activity of multiple muscles. fEMG offers the most direct, feasible measure of motor control to the extent that it quantitatively represents the activity of the central nervous system, called the pooled firing rate (PFR). The key problem in taking this approach is therefore to derive the best estimate of the PFR from the fEMG signals. By adding a priori information, it is possible to utilize these surface potentials for monitoring and assessment of motor functions of the CNS, in practical medical terms in diagnostic evaluation of motor disorders.

Functional electromyography relies on the motor act as its organizing framework, and seeks to document activity in as many muscle groups as practical. In fEMG, emphasis is placed on broad representation (i.e., patterns) of motor activity, with less concern about the selectivity of the recordings; thus, surface electrodes are used to detect the activity to be monitored. Key to the success of this approach is the utilization of motor acts that demonstrate the desired range of voluntary and reflex motor behaviors. Use of voluntary tasks that are natural movements and cover the range of desired activities enables quantitative comparison to healthy subject movements.

Practical implementation of fEMG has been carried out in the brain motor control assessment (BMCA) protocol, used now for more than four decades, rigorously applied by well-trained technologists, with scripted subject instructions to minimize the inter-test and cross-population variability (Sherwood, et al., 1996). Based on spinal motor cell output, the protocol begins with relaxation. It continues with volitional attempts to move limbs, followed by passive limb movement, then reflex elicitation. The protocol was initially intended to evaluate individuals with severe spinal cord injuries who are seriously disabled but has been applied subsequently to other upper motor neuron lesions (Bacia et al., 1998; Lin et al., 2006; Tang et al., 2012). It is designed to be relatively insensitive to training effects, as the voluntary procedures are so simple, no training is needed to perform well, and has been demonstrated to be stable (Sherwood et al., 1997, Lim et al., 2005a) and sensitive to abnormal motor function (Sherwood, 2000).

Full bandwidth surface EMG data are recorded from eight to 32 muscles at a 2000 samples/second rate. For analysis, the full bandwidth data is converted into a summary file using a root mean square algorithm, resulting in an effective 20 Hz data sampling rate. Using markers and identification provided during recording, each individual maneuver (motor act) is isolated and extracted (all channels). A single scalar value (number) is created for each phase of each maneuver for each muscle by averaging the activity over the 3 second response window that begins with the event mark. These data are corrected by subtracting any activity in the one-second window immediately prior to the beginning of the maneuver. The resulting set of numbers, one per muscle (channel) are used to create a response vector (Lee et al., 2004). By comparing that vector to a prototype response vector, one can quantify the deviation from
neurologically intact subjects and hence quantify the quality of motor control (ibid.). This method has been used to characterize severity of a spinal injury (Lim et al., 2005b) and to follow subjects’ recovery (McKay et al., 2011).

Dr. Meta Dimitrijevic described a method of whole-hand electrical afferent stimulation to modify abnormal motor function after stroke, commonly referred to as mesh-glove stimulation after the mechanism used to deliver the stimulation. (Dimitrijevic, 1994). While the stimulation is delivered at a sub-perception level, it nevertheless has been shown to be physiologically active, including changes in EMG results (Dimitrijevic et al, 1996), fMRI changes (Golaszewski et al, 1999), and motor (Golaszewski et al, 2010) and sensory (Dimitrijevic et al., 1996a) evoked potentials. However, more recent works have shown that higher stimulus levels may be even more physiologically active (Golaszewski et al., 2012).
References and Selected Bibliography:


