Estimation of monopolar signals from spincter muscles and removal of common mode interference

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ESTIMATION OF MONOPOLAR EMG SIGNALS FROM SPHINCTER MUSCLES

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1. INTRODUCTION
Surface electromyogram (EMG) is usually recorded by means of spatial filters with vanishing sum of weights. More information could be extracted from monopolar signals measured with respect to a reference electrode away from the muscle. Under some assumptions, surface EMG detected along a line parallel to the fiber path has zero mean value in space at any time. This property is a constraint which can be used to estimate monopolar signals from single differential (SD) EMG signals and is satisfied in the case of a circumferential electrode array surrounded by a circular muscle.

2. METHODS
The problem of estimating monopolar signals \( \hat{m}(t) \) from SD \( \tilde{s}(t) \) is not well posed. Indeed, there are infinite solutions, as an arbitrary function of time \( f(t) \) can be added to the monopolar signals without affecting the SD signals

\[ x(t) = m(t) + f(t) - (m(t_0) + f(t_0)) = m(t) - m(t_0) \]

SD signals from an array of N electrodes can be expressed in terms of monopolar signals as follows

\[ \tilde{s}(t) = \mathbf{A} \hat{m}(t) \]

Matrix \( \mathbf{A} \) cannot be inverted as it has a vanishing eigenvalue, associated to an eigenvector with constant entries.

Nevertheless, the pseudoinverse of matrix \( \mathbf{A} \) can be evaluated and monopolar signals can be estimated as

\[ \hat{m}(t) = \mathbf{A}^+ \tilde{s}(t) \]

Inner product

Under the assumption that the volume conductor is space invariant, the monopolar surface EMG detected along a curve parallel to the fiber path has zero mean value in space at any time.

3. RESULTS

Application to simulated SFAPs

Additive white Gaussian noise

Figure 3 Performance of the method. Mean and STD of the RMS error in estimating monopolar from SD SFAP corresponding to 88 positions of simulated fibers (depth between 2 and 8 mm within the muscle with 1 mm step, distance of the fibers from the detection electrodes in the axial direction between 0 and 1 mm with 1 mm step).

Application to simulated free MUAPs and interference signals

A) Example of simulated MUAP. B) Example of estimated interference signal.

Figure 4 A) Application of the method to a MUAP (MU constituted by 154 fibers) and B) to an interference signal (60 MU, force level 40% MVC). SD signals were obtained from the simulated monopolar signals, and then monopolar signals were reconstructed.

Considerations on the estimation error

The estimation error is in the sum of the "approximation error" due to sampling and the "noise error" due to addition to the result of the estimated Gaussian with zero mean and standard deviation (7). The "approximation error" is the common mode present in the vector of sampled monopolar signal and reduces with increasing number of channels.

4. CONCLUSIONS
Under the hypothesis of space invariance of the volume conductor, monopolar signals detected along the direction of the muscle fibers with an array covering the entire spatial support of the potential distribution have vanishing spatial mean at any time. This provides a constraint for estimating monopolar SD signals from sphincter muscles.

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