VARIABILITY OF SUPERPOSITION OF ACTION POTENTIALS, THEORETICAL MODEL

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Abstract

Linearity of values of rectified and integrated EMG signals with frequency of incidence of action potentials in muscle fibers and the effect of moving average window width on the range of values of integrated signals was tested on theoretical model. Our simulations of 4 overlapping single units multipotential signal demonstrated that integrated EMG signals are only approximately linearly proportional to the frequency of action potentials in the superposition - multipotential. The width of moving average window influences the range (dispersion) of integrated values (their accuracy). Quality of EMG recordings, the frequency (the number) of action potentials as well as the width of moving average window increase the accuracy of the determination of integrated EMG signal.

Key words: action potential, superposition, linearity, moving average window, accuracy

Introduction

Nerves conduct signals in form of action potentials. Action potential is a basic manifestation of excitatory tissues activity. It represents an essential element of encoding and transmission of informations in neural system and it also represents the first stage of muscle contraction triggering. It is generally assumed (in the field of nerve modeling as well) that the nerve compound activity (multipotential) is a linear superposition of single fiber action potentials [1]. Elektromyogram (EMG) usually represents a complex electrical biosignal, the results of superposition of action potential trains recorded from muscle fibers located near the electrode and generated by active motor units. The motor unit consists of the motor neuron and the muscle fibres innervated by its axonal branches. The number of muscle fibres in the motor unit ranges widely across human (and animal) muscles. The muscle fibres of each motor unit are intermingled with fibres of other motor units so fibres belonging to several different motor units are close to each other [2]. The assumption of linearity of summation of their activation is crucial for evaluation of intensity of the whole muscle activity, for decomposition of multiunit EMG, for computer simulations and mathematical models [1]. In this paper, we attempted to study linearity of superpositions of action potentials from few motor units recorded at the electrode using computer theoretical model. We hypothetized that linearity of superposition of action potentials as well as its variability depends on frequency of action potentials and on the width of integrated windows.

Methods

The model consisted of five waveforms. Four of these waveforms simulated single unit EMG signals and the fifth waveform represented algebraic summation of the four single units. A three phase shape of action potential (single units) was chosen. It corresponded to the in vivo recordings [3] and lasted 5 ms (the 1st and the 3rd waveform) and 7 ms (the 2nd and the 4th waveform) [3]. All waveforms were shifted in time from the 1st one. The second started 4 ms, the third 1 ms and the fourth waveform 5 ms after the 1st one. The frequency of their incidence was 5 - 75 Hz (the 1st and the 3rd one) and 9 - 135 Hz (the 2nd and the 4th one) [4]. The integrated waveform represented rectified (absolute values) and averaged signal. We employed 3 windows widths - 1 s, 200 ms and 40 ms. Moving average window (MA) was shifted by 0,01 ms each step. Theoretical model was built and simulations were performed in PC environment MATLAB.

Results

First, we verified the linearity of superposition of action potentials. We tested the linearity of action potential integration for each of four single unit waveforms as well as the linearity of moving average values of their superposition. We increased successively the frequency of action potentials and we acquired the rectified and moving average values of all five waveforms. The width of moving average window was 1 s. Using this window width the integrated values of four single unit waveforms increased linearly with the frequency of action potential incidence. Moving average values (integrated signal) of superposed waveform increased approximately linearly with the frequency of the occurence of action potentials, however, with some variability (errors) due to overlaping of positive and negative components of individual action potentials (Figure 1).

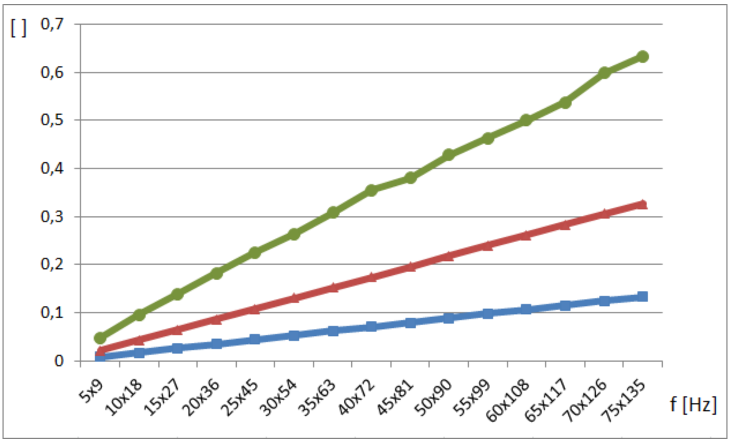

Figure 1: Relation of integrated EMG signal values and the frequency of action potentials. Blue (square) line - values of waveforms (the 1st and the 3rd single unit train) with 5 ms duration of action potentials, red (triangle) line - values of waveforms (the 2nd and the 4th single unit train) with 7 ms duration of action potentials, green (circle) line - superposed waveform.

Second, we tested an impact of the width of moving average window on the interval wherein values of integrated waveform can fall. We used moving average window widths 200 ms and 40 ms. Superposed waveform was rectified and integrated. Then, we found minimal and maximal values in the entire range of integration. These values (the differences maximum minus minimum) were determined for all frequencies and for both moving average window widths. This way 2 sets of intervals were obtained (Figure 2a). The variability of differences (maximum minus minimum) with 200 ms moving average window was 3.2 fold less than that with 40 ms moving average window. Subsequently we attempted to express the inaccuracy of integration performed using 200 ms and 40 ms windows at superposed waveform. Reference (the accurate) value was obtained with integration of the signal using the window width of 1 s (all action potentials were taken). The values obtained with 200 ms and 40 ms, which differed the most from the reference value were calculated and these deviations were expressed in percentage. We determined the deviations for all 15 pairs of frequencies. The deviation at 40 ms window and the lowest frequency of incidence of action potentials was 259 %, while using 200 ms window the deviation was only 17 %. The deviations decreased with higher frequency of action potentials in the waveforms in both cases (200 ms and 40 ms moving average window), and at the highest frequency it was 1,55 % for 200 ms window and 10,2 % for 40 ms window (Figure 2b).

a) b)

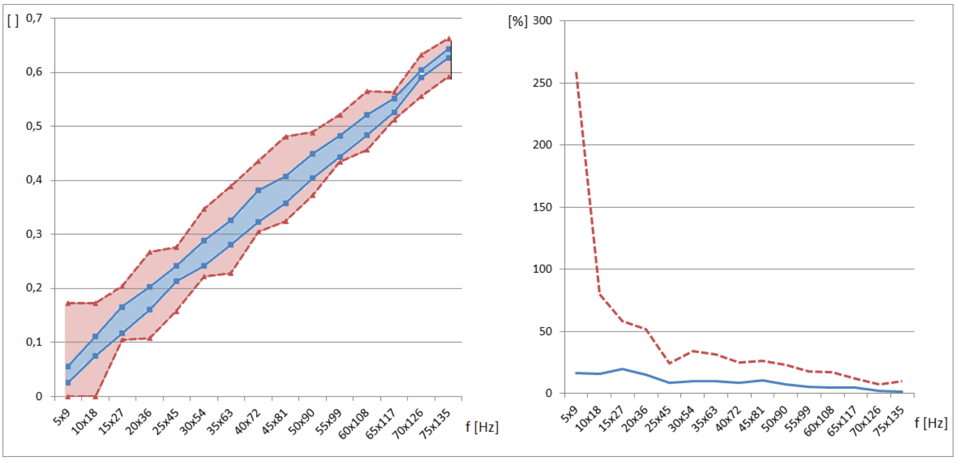

Figure 2: Inaccuracy of moving average values (deviations) related to different moving average window width and frequency of action potentials. a) The width of interval with 200 ms window (blue) was 3.2 fold narrower than using the with of 40 ms window (red). b) With the increasing frequency of incidence of action potentials the deviation was decreasing in both cases, 200 ms window - blue unbroken line, 40 ms window - red broken line.

Discussion and conclusions

Our simulations demonstrated that moving average values of four raw single unit waveforms increased linearly with the frequency of action potentials. Similar linearity, however, with some variation (inaccuracy) was found also for integrated multipotential EMG signal (superposition of individual single units). The width of moving average window significantly influences the range (dispersion) of integrated values. Approximately three fold higher variability was found for the moving average window width of 40 ms compared to that for 200 ms window. Our results are consistent with experiences obtained during experiments and analyses of data on animals (reference; our own data). Quality of EMG recordings depends on both the frequency of action potentials (possibly the number of action potentials recorded) and the width of moving average window. The accuracy of the determination of integrated EMG signal increases with the number of action potentials taken and with the width of moving average window. These two factors have to be taken into serious consideration in addition to the duration and variability of analysed signals (short bursts with steep start and finish [5]) during EMG and potentially electroneurogram analyses.

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