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A Method for Quantitative SEMG Decomposition and MUAP Classification during Voluntary Isovelocity Elbow Flexion

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***Abstract*—The purpose of this study was to develop an algorithm for surface electromyogram (SEMG) decomposition and classification of surface motor unit (MU) action potential (MUAP) detected during isovelocity elbow flexion.**

In our proposed algorithm, firstly the measured SEMG was extracted for 3 seconds by every 1.5 seconds. SEMG was decomposed with Independent Component Analysis (ICA) technique, and classified with template matching. Finally, the MUAP trains were identified under the firing time of the MUAPs classified in each extracted period.

The SEMG was measured from the biceps short head muscle during voluntary elbow flexion of 0 to 90 degrees at constant velocity 9 degree/s against a constant load torque of 10%MVC and the MUAPs were classified with our proposed algorithm. As a result, calculated MUs firing rates were almost same as the results in the previous studies. It was shown that the proposed algorithm was useful for decomposing SEMG detected during flexion movements.

I. Introduction

It was important to investigate behavior of motor units (MUs) in the physiology and medicine. In many studies, measured surface electromyogram (SEMG) was analyzed and characteristics of the MUs behavior were observed [1]. Most studies of MUs activity in humans have been restricted to isometric conditions in which the length of the muscle does not change. We have very little information of motor units behaviors during movement in which the length of the muscle changes. In the previous study, the MUAPs were measured from tibialis muscle during ankle joint flexion [2]. However range of angle during flexion was very small because needle electrodes were used for the measuring MUAPs. We investigated motor units behaviors in biceps short head muscle and showed that firing rates (FR) of activated MUs were almost same during isovelocity elbow flexion of 0 to 120 degrees [3], where each MU was identified by visual observation. The measured MUAP waveforms were gradually changed and it was difficult to do SEMG decomposition quantitatively.

In order to decompose the SEMG quantitatively during voluntary isovelocity elbow flexion, attention was given to the fact that MUAP waveforms of one MU extracted for short period during isovelocity movements were almost same shape, therefore in this short period we analyzed the SEMG using the quantitative decomposition techniques under the isometric contraction. We could decompose the SEMG during isovelocity elbow flexion by unifying the SEMG decomposition result of each short period.

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II. Methods

A. Measurementof SEMG

< Experimental Set-up >

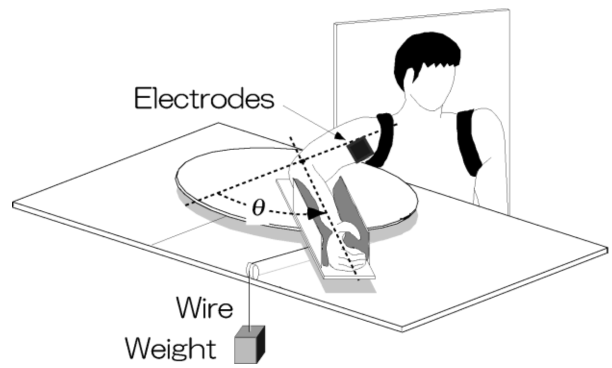


Figure 1. Schematic overview of the experimental setup.

The task given a subject was isovelocity flexion of the elbow joint in a horizontal plane and the SEMG was measured with a surface electrode array. A schematic diagram of the experimental setup is shown in Figure 1. The subject's right forearm was fixed on a disk which could rotate in the horizontal plane. The wire attached a weight was connected to the disk and his forearm was pulled under a constant torque during flexion movement.

The eight-channel surface electrode shown in Figure 2 was used; the array consisted of 16 stainless steel electrode poles of 1 mm diameter and the electrode separation was 2.54 mm. This electrode was affixed to the skin over the biceps short head muscle belly so that the muscle innervation zone would not pass between pairs of electrodes during the elbow flexion. The SEMG signal was amplified with the gain 60 - 80 dB and the cut off frequency was set at 800 Hz.

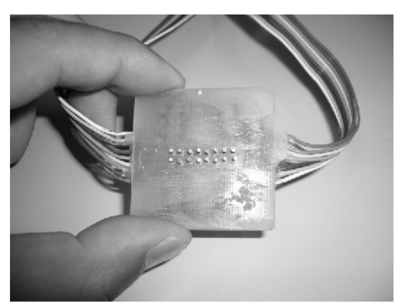


Figure 2. Eight-channel bipolar surface electrodes.

< protocol >

The experiments were performed with one healthy subject who gave informed consent and the investigation was approved by the local Ethics Committee.

The subject was instructed to maintain the elbow joint at a predetermined angle (approximately 5 degree flexion from full extension) and then to flex the elbow joint smoothly to approximately 90 degree at constant angular velocity (9 degree/s) against the applied load torque (10% MVC). Finally, he stopped the flexion at about 90 degrees and kept the elbow joint at that position. Note that the start angle was subtracted from the true elbow angle to make the start position 0 and the final position of 90 degrees.

Before beginning actual measurements, a subject trained sufficiently to perform smooth motions. At the beginning of the experiments, torque during maximum voluntary isometric contraction (MVC) was measured at an angle of 90 degrees.

B. Analysis of SEMG

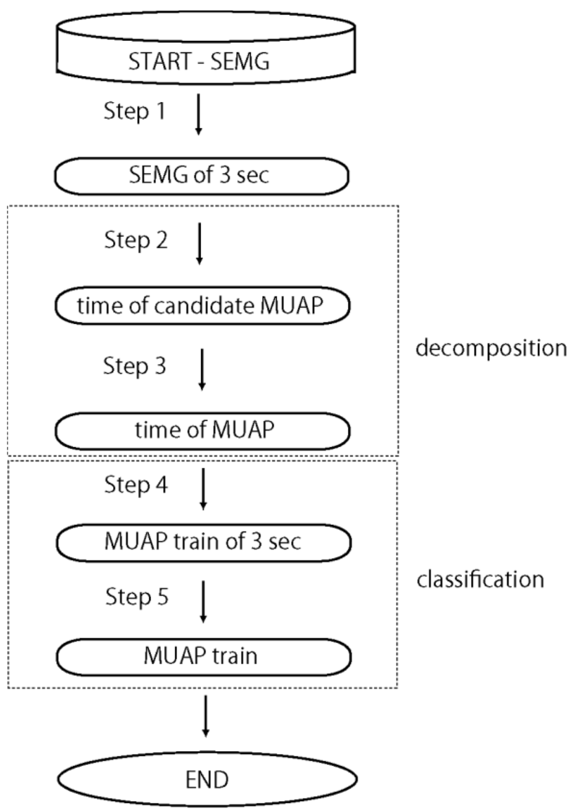


Figure 3. We developed the algorithm in order to monitor motor unit activity continuously over a sufficient large range of motion.

Figure 3 shows the flowchart of the algorithm. In the algorithm, SEMG signal is decomposed from Step 2 to 3, and MUAP is classified from Step 4 to 5.

Step 1:

In Figure. 4, measurement time of SEMG was 10.5 s. This time period was too long to analysis SEMG at once because the length of the muscle changes, so that the SEMG clipped for decomposition time at number of the time *j*. ${}^{j}T_d$ was extracted at interval time of 3.0 s. It was necessary to connect MUAP trains (MUAPTs) of ${}^{j}T_d$, so coupling period ${}^{j}T_c$ is set at 1.5s.

<decomposition of SEMG >

Decomposition of SEMG was performed at Step 2, and Step 3.

Step 2:

Independent component analysis (ICA) [4]–[7] was applied to SEMG of 3 s, and ICA components which was used to search time of candidate MUAP were obtained with calculation of kurtosis as follows;

For univariate date $y_1, y_2, \ldots, y_N$, *k*-th moment M_k is described as Eq. (1):

$$M_k = \frac{1}{N}\sum_{i=1}^{N}(y_i - m)^2 \quad (1)$$

where *m* is the mean, and *N* is the number of data points.

And, standard deviation is settled at σ, then kurtosis k_r is described as Eq. (2) [4],

$$k_r = \frac{M_4}{\sigma^4} - 3 \quad (2)$$

Considering the measured SEMG, and result of ICA as shown in Fig. 5, using Eq. (2) and calculating k_r of each ICA component of Fig. (b), the results are as follows: IC 1 of k_r was 8.35, IC 2 of k_r was 2.85, IC 3 of k_r was 1.00, IC 4 of k_r was 0.48, and IC 5 of k_r was 0.11.

Taking the results into consideration, k_r which was the useful ICA components for SEMG decomposition was larger than 1.0.

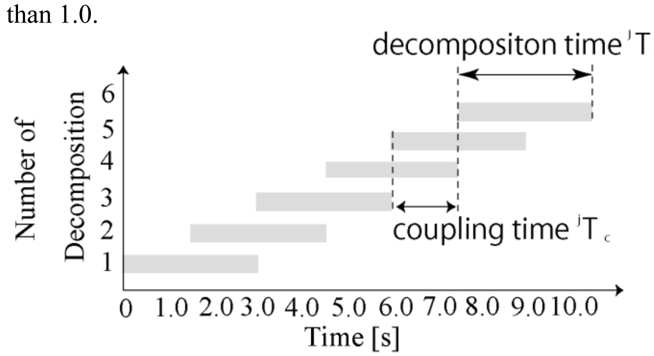
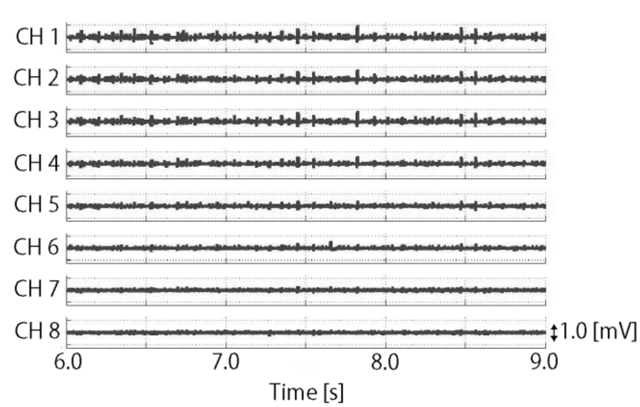
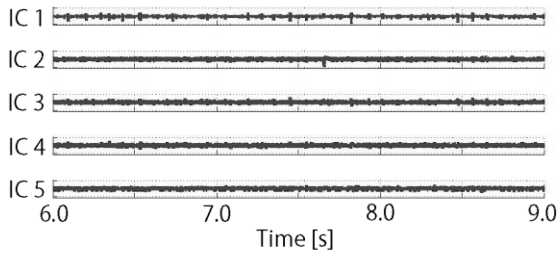


Figure 4. Algorithm of decomposition.



(a)



(b)

Figure 5. Observed SEMG (a) and ICA signals (b).

Maximum value in the each selected independent component (IC) was calculated. If the value in the IC was larger than 20% of the calculated maximum value, the waveform which yielded this value was extracted.

In Figure. 6, the waveform shows not only MUAP but also ICA signals based on the firing of MU [8]. In the ICA signals, "Time of candidate MUAP" was determined when the highest value is measured in the constant range.

Step 3:

In the SEMG, "Time of MAUP" was determined as ${}^{i}\mathrm{t}_{\mathrm{ch}}^{\mathrm{p}}$ when the highest value is measured in the constant range. ${}^{i}\mathrm{t}_{\mathrm{ch}}^{\mathrm{p}}$ was quantitatively determined with considering the "Time of candidate MUAP". The constant time rage *R* was used to extract MUAP waveforms.

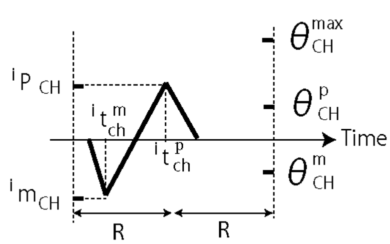


Figure 6. MUAP waveform.

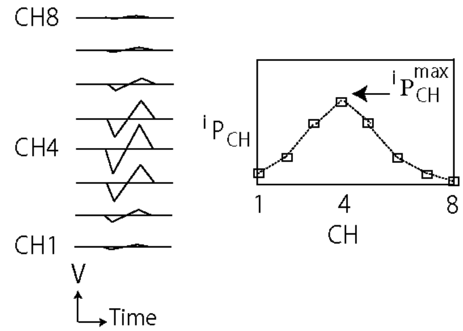
<classification of MUAP >

Step 4:

In this step, the extracted MUAPs were classified with template matching technique.

At the "time of candidate", SMUAP profile [8] was plotted as shown in Figure 7, in this figure maximum value of each channel (${}^{i}P_{CH}$) was calculated within the time range from ${}^{i}\mathrm{t}_{\mathrm{ch}}^{\mathrm{p}}$ to constant range (R = 4.0 ms). Maximum value of SMUAP profile was determined as ${}^{i}\mathrm{P}_{\mathrm{CH}}^{\mathrm{max}}$.

Considering that it is important to do pattern mach carefully, templates are made with using the channel ${}^{i}\mathrm{P}_{\mathrm{CH}}^{\mathrm{max}}$ and next two channels. The higher ${}^{i}\mathrm{P}_{\mathrm{CH}}^{\mathrm{max}}$, the faster the tern of calculation become. If the correlation coefficient was larger than 80%, then the two MUAPs are defined as yield by one MU. MUAP train of 3 s was made from classification results.



(a) (b)

Figure 7. MUAP profile.

In the algorithm of this study, the correlation coefficient between base waveform and the other waveforms were calculated in turn. Base waveform was selected in the order from high value of $P_{CH}^{\max}$ to low value of it at 3.0 s period, because compared with ascending order calculations, descending order calculations classified MUAPs clearly like human visual method. Taking the examination results of MUAP classification into account, we determined that range R was 4.0 ms, and threshold value θ_{CH}^{p} was 200 μ V.

Step 5:

In order to decompose SEMG for 10.05 s, it was necessary to merge each 3.0 s MUAP trains (MUAPTs). Figure 8 shows schematic drawing of this process. Each bar represents one firing and firings of the same motor unit are aligned horizontally. At some points in this figure, the firing time of MUAPT 1 is exactly the same as MUAPT 2 and 3.

The method for coupling MUAP trains (MUAPTs) of next period, rarely there were a few coupling candidates of MUAP trains. It was necessary to calculate the difference between the base MUAPT and other candidate MUAPTs so that templates of each MUAPTs were made.

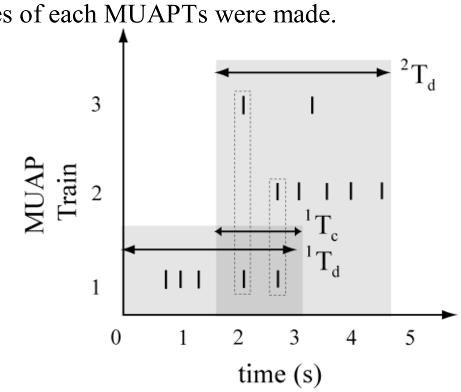


Figure 8. The method for connecting MUAP trains of two different periods at coupling time.

III. RESULTS

In this study, we instructed a normal subject to flex the elbow joint from 0 to 90 degree against constant load torque at 10%MVC with isovelocity of 9.0 degree/s, and measured SEMG of the biceps short head muscle.

It was used to retain the MUAPs belongings to the target MUAP and remove both the noise and the low-amplitude

MUAPs that did not reach the given thresholds. An example of the decomposition result is shown in Figure 9. MU1(○) was fired at 7.40 s, 7.49 s, 7.50 s, and 7.59 s, and at this time each maximum value was 0.317 mV, 0.308 mV, 0.283 mV, and 0.347 mV. Each Max Ch is 1.

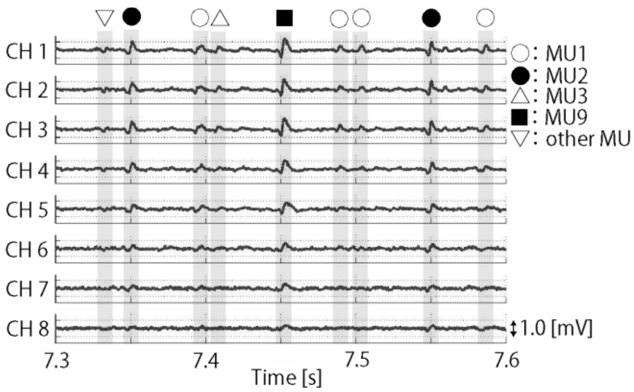


Figure 9. Typical results of eight-channel SEMG. Firings of five different MUs could be identified.

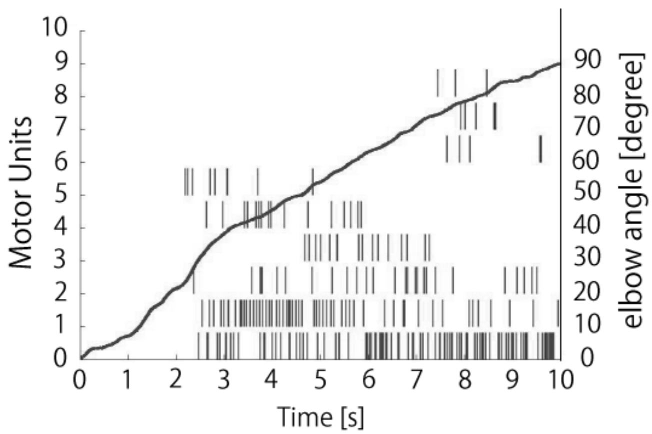


Figure 10. An example of time course of elbow angle and activities of single MUs in isovelocity elbow flexion movement. Solid lines: elbow joint angle (average velocity was approximately 9 degree/s). Identified firings of nine MUs are shown. Each bar represents one firings and firings of the same MUs are aligned horizontally.

Table 1 MUAP Train

MU Number	Start Time [sec]	Stop Time [sec]	Frequency [Hz]	Standard deviation [Hz]
1	2.4761	10.4557	18.779888	12.889876
2	2.5449	10.3524	12.183623	8.251018
3	2.3696	10.2901	7.457199	8.618157
4	4.6882	7.277	6.741654	3.939102
5	2.6294	5.8541	8.285944	7.210571
6	2.1963	4.8469	6.137574	6.753165
7	7.6365	10.2682	8.450301	15.637005
8	7.9317	8.6573	4.812042	5.320761
9	7.4525	8.4746	1.411082	1.353419

Firings of five different motor units were identified. Firing rate was calculated as the inverse of the interpulse (firing interval).

It was often found that MUs fired for a very short period. An example is shown in Figure 9, where two firings of the same motor unit could be identified clearly.

In Figure 10, a typical classified result (velocity of 9.0 degree/s; load torque of 10% MVC) is shown, and firings of nine motor units, MU 1 to MU 9 were identified. The detail information of this MUAP trains are shown at table 1. The results are in agreement with the generally accepted behavior of MUs firing rates (FR).

IV. Conclusion

We developed an algorithm for the quantitative extraction and classification of individual MUAPs during the movement of elbow flexion from SEMG. In order to show usefulness of this algorithm we measured SEMG detected from the biceps short head muscle during voluntary elbow flexion of 0 to 90 degrees at constant velocity 9 degree/s against a constant load torque of 10%MVC and MUAPs were classified with our proposed algorithm. As a result, calculated MUs firing rates were almost same as the results in the previous studies. It was shown that the proposed algorithm was useful for decomposing SEMG detected during voluntary isovelocity elbow flexion.

Acknowledgment

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