Investigation of a Multichannel Surface Electromyogram Analysis Method Considering Superimposed Waveforms in a Elbow Flexion Movement

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Keywords: Surface EMG, Superimposed Signals.

Abstract: The purpose of this study was to develop a method of decomposing the surface motor unit acton potential (SMUAP) of a biceps brachii short head muscle when the distance from the surface electrodes to the motor units (MUs) changes during voluntary isovelocity elbow flexion. In the preparatory study, a subject's elbow flexion movement had changed the shape of the SMUAP, which was probably made by a single MU larger than the previous study. Thus, we had to develop a SMUAP decomposition method that focused on tracking the SMUAP waveform changes and superimposed signals. The developed SMUAP decomposition algorithm was based on a sequentially modified template matching method, considering the superimposed signals. This was applied to the measured SMUAPs. The MU firing rates calculated with our algorithm were almost the same as those of previous physiological studies; our algorithm was capable of decomposing SMUAPs when the waveform of the SMUAP was generated from a single MU and responded with each change in firing time.

1 INTRODUCTION

In physiology and medicine, methods to investigate the behaviors of motor units (MUs) are desired. Studies have shown that high-density surface electrodes are suitable for analyzing the characteristics of MUs during isometric contraction (Merletti and Parker, 2004).

Needle electrodes have been used to analyze the motor unit acton potential (MUAP) behavior from the tibialis muscle during ankle joint flexion [Kato, Murakami, and Yasuda, 1985). However, needle electrodes restricted the angle to a small range.

To solve this problem, we used multi-channel surface electrodes to investigate the behavior of the MU in the biceps brachii short head muscle. Our results showed that the firing rates (FRs) of activated MUs were almost the same when the degree of elbow flexion varied from 0 to 120 degree; additionally, surface MUAPs (SMUAPs) were identified by visual observation (Okuno, Maekawa, Akazawa, Yhoshida, and K. Akazawa, 2005). The measured SMUAP waveforms changed gradually; thus, it was difficult to perform SMUAP decomposition quantitatively.

In this study, we developed an algorithm to decompose the SMUAPs quantitatively during voluntary isovelocity elbow flexion. This algorithm was based on the similar shape of SMUAP waveforms of a single MU extracted for a short period during isovelocity movements (Akazawa and Okuno, 2013).

Notably, in some subjects whose fat tissue was thin, the shape of the SMUAP was most likely generated by a single MU; in this case, the waveform shapes changed, making it difficult to decompose the SMUAPs. Thus, further adjustments to the algorithm were required to address this issue.

Akazawa, J. and Okuno, R.
Investigation of a Multichannel Surface Electromyogram Analysis Method Considering Superimposed Waveforms in a Elbow Flexion Movement.
DOI: 10.5220/0006634901950200
In *Proceedings of the 11th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2018) - Volume 4: BIOSIGNALS*, pages 195-200
ISBN: 978-989-758-279-0

2 METHODS

2.1 Experimental Setup

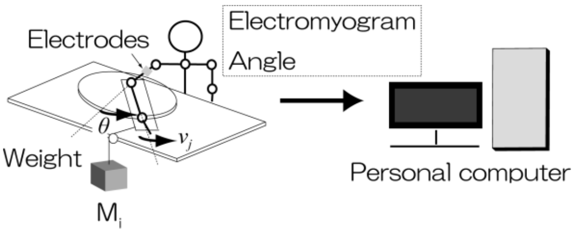

Figure 1: Schematic overview of the experimental setup.

A schematic diagram of the experimental setup is shown in Fig. 1. The subject was instructed to flex the elbow joint smoothly to approximately a 110° angle at constant angular velocity (5°/s) against 10% of the maximum voluntary contraction (MVC). The experiments were performed with one healthy subject, who gave informed consent. The investigation was approved by the local Ethics Committee of Meiji University of Integrative Medicine.

An eight-channel surface electrode was used. The surface electromyogram (SEMG) signals were amplified with a gain of 80 dB. The band pass filter was set at 43 Hz–2.8k Hz.

2.2 Algorithm

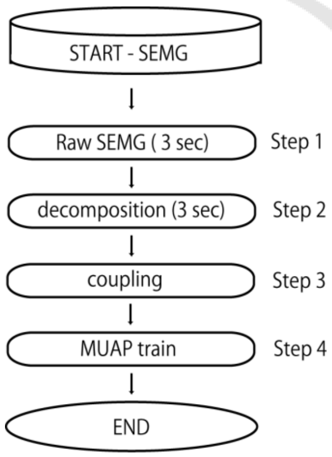

Figure 2: Algorithm to monitor motor unit (MU) activity continuously over a sufficiently large range of motion.

The algorithm shown in Fig. 2 was developed based on our previous method [Akazawa J., Okuno R., 2013], with several modifications. The algorithm steps are described below.

When identifying the action potential of a single motor unit, we use the SMUAP Profile to extract the characteristics of each SMUAP.

Fig. 3 shows the method for making the SMUAP profile [Akazawa, Sato, Minato, and Yoshida, 2005]. The SMUAP profile consists of both plus and minus amplitude components, because the minimum potential ($^i m_{CH}$) was sometimes larger than maximum potential ($^i p_{CH}$) from the preliminary experiment. The eight-channel SEMG is shown in Fig. 3(a). Fig. 3(b) shows the parameter for detecting the SMUAP. The maximum potential at t = $^i t^p_{CH}$ is denoted by $^i p_{CH}$, and the minimum potential at t = t = $^i t^m_{CH}$ is denoted by $^i m_{CH}$. The threshold parameters were θ^p_{CH} and θ^m_{CH}. In Fig. 3(c), the values of $^i p_{CH}$ were plotted against each channel to create a SMUAP profile. $^i p^{max}_{CH}$ is the maximum of $^i p_{CH}$. In Fig. 3(d), the values of $^i p_{CH}$ were plotted against each channel to create a SMUAP profile. $^i m^{min}_{CH}$ is the minimum of m_{CH} .

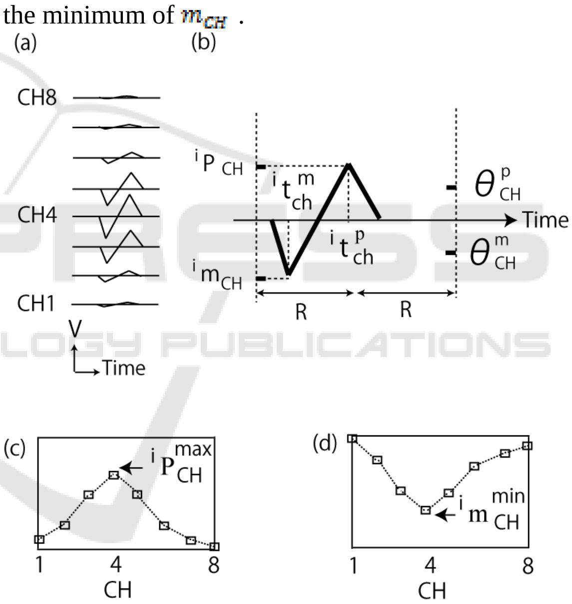

Figure 3: Method for creating an SMUAP profile from measured surface electromyogram (SEMG) signals.

Step 1:
In Step 1, the SEMG is measured for 30.0 s. The SEMG is used to retain the MUAPs that belong to the target MUAP and remove both the noise and low-amplitude MUAPs that do not reach the given thresholds.

Step 2:
We calculate the coincidence between SMUAP profiles to decompose the SMUAPs. The performance index (PI) characterizing the fitness between two SMUAPs is given by Eq. (1):

$$PI = \left(1 - \left|\frac{\Phi_{base} - \Phi_{candidate}}{\Phi_{b}}\right|\right) \times 100 \ \ldots (1)$$

If the *PI* is larger than the threshold value, then both Φ_{base} and $\Phi_{candidate}$ are defined as generated by a single MU. Both previous (Akazawa J., Okuno R., 2013) and present decomposition methods are shown at Fig. 4. The parameters are described as follows.

$SMUAP_{t_i}^{MU_i}$: Potential distribution of the SMUAP.
MU_i : Number of the MU.
t_j : firing time of the MU.

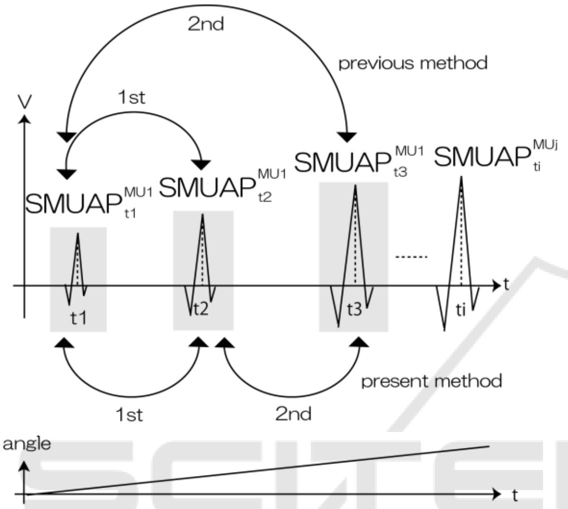

Figure 4: Surface motor unit action potential (SMUAP) decomposition method: previous method versus present method.

When the SMUAPs of a single MU were decomposed in a previous study (Akazawa J., Okuno R., 2013), Φ_{base} did not change. In the present study, we used a sequential method to account for changes in Φ_{base} . As such, our sequentially modified template matching method was expected to be more robust than our previous method (Akazawa J., Okuno R., 2013)when the amplitude of the SMUAP increases or decreases upon firing.

In Step 2, synthetic waveforms are created using templates based on the single motor unit detected at Step 2.

The difference between the waveforms of this synthesized waveform and the measured superimposed waveform are calculated and then decomposed. As shown at Fig. 5, a superimposed waveform is created by adding SMUAP of Motor Unit 01 (MU01) and MU 02 which are single motor units. Identification processing is performed by calculating the difference between the waveforms of the superimposed waveform and the measured superimposed waveform.

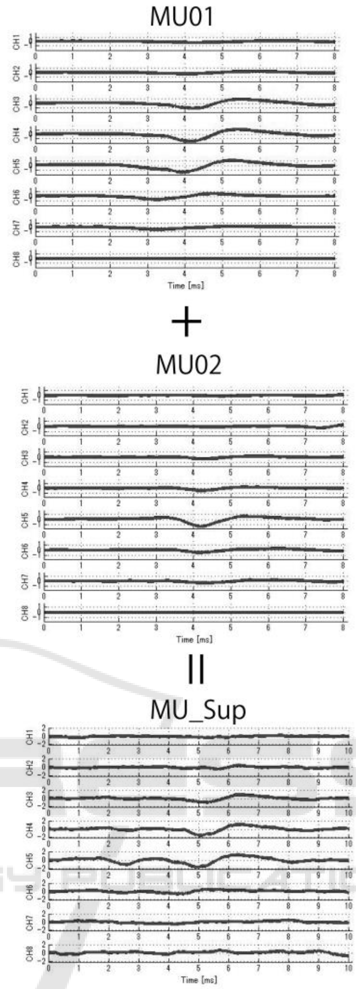

Figure 5: Creation of superimposed waveform.

Step 3:
\In Step 3, coupling is used to connect the MUAP trains (MUAPTs). As shown in Fig. 6, since the muscle length changes, the time period of 30.0 s was too long to decompose all of the SMUAPs at once. Thus, short-period (3.0 s) signals were used. The coupling period to connect the MUAPTs was set to 1.5 s.

To decompose the SEMG for 30.0 s, it was necessary to merge each 3.0-s MUAPT. Fig. 6 shows a schematic diagram of this process. Each bar represents one firing. Firings of the same MU were aligned horizontally. Notably, at some points in Fig. 6, the firing time of MUAPT 1 was the same as in MUAPT 2.

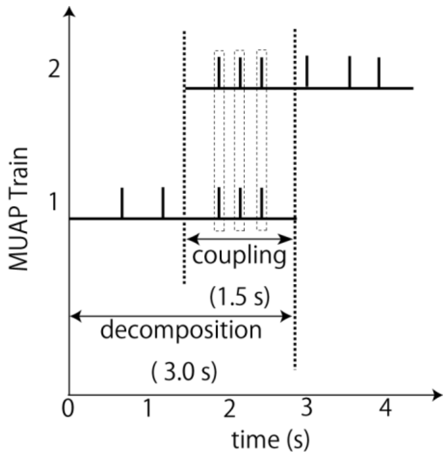

Figure 6: Schematic diagram for the coupling.

Step 4:
In Step 4, the firing patterns of all identified MUs are plotted as MUAPTs to resolve the activity patterns of the MU.

3 RESULTS

In this study, we instructed a normal subject to flex the elbow joint from 0 to 110° against a constant load torque of 10% MVC with an isovelocity of 5.0°/s. The SEMG signal was detected with an electrode array from the biceps brachii short head muscle. When the elbow joint angle reached 40° at 9 s, the active MU was observed.

As a subject flexed the elbow smoothly, the SMUAPs that had a large amplitude at CH1 at 10 s changed smoothly from a low channel number to a high channel number. As the elbow angle increased, ${}^{i}p_{CH}^{max}$ moved from a small channel number to a large channel number.

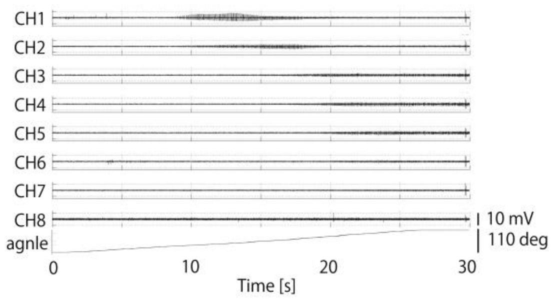

Figure 7: SEMG signals obtained from the biceps brachii short head muscle during voluntary isovelocity elbow flexion.

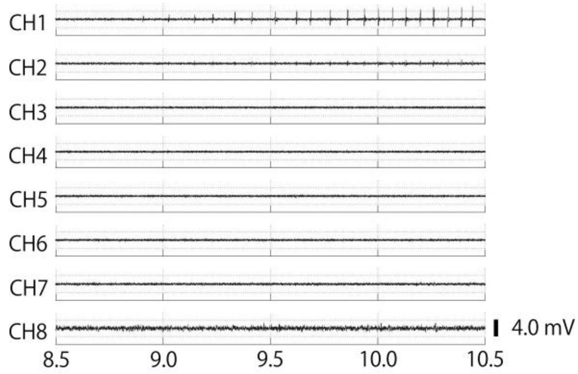

Figure 8: Extracting the SMUAP signals. The active MU was observed from roughly 9 s.

Fig. 8 shows the extracted SMUAPs. Our algorithm revealed that these SMUAPs were generated by a single MU. On the left side of the figure, the amplitude becomes larger over time; whereas on the right side of the figure, the SMUAP retains the same shape. Using our previously developed algorithm (Akazawa J., Okuno R., 2013), we calculated the rate of fitness between the two SMUAPs. The rate of fitness decreased as a function of elbow flexion angle because the SMUAP of a single MU changed rapidly. Thus, it was necessary to improve the previous decomposition method (Akazawa J., Okuno R., 2013).

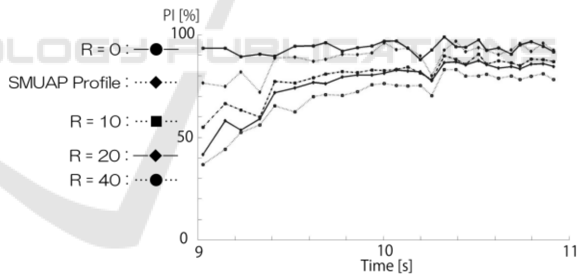

Figure 9: Relationship between the range and performance index PI [%].

Fig. 9 shows the relationship between the range R and the SMUAP profile used to extract the SMUAP characteristics and the PI [%] calculated from the difference of the two SMUAPs. When the range changed from 10 to 40, the ratio increased from 9 to 10 s. On the other hand, when the range was set at 0, PI held a nearly constant value.

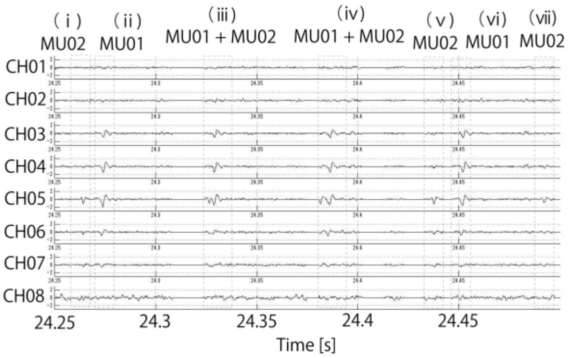

Figure 10: Our developed algorithm decomposed the MU action potentials.

A typical SEMG record of biceps brachii muscle (BIC) is shown in Fig. 10. To determine whether SMUAPs were from the same MU, individual SMUAP shapes (channels 1–8) shapes were compared by the algorithm. We detected nine SMUAPs from two MUs.

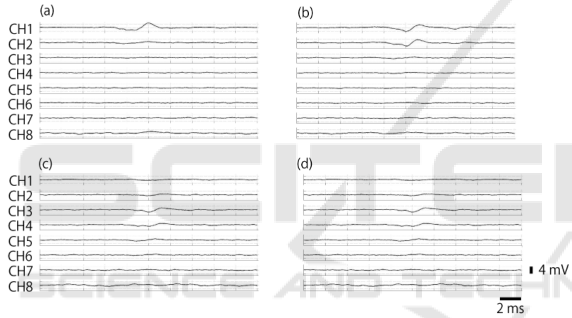

Figure 11: SMUAP wave shape of the MU01 observed at four points.

Fig. 11 shows that the SMUAP waveform of MU01 changed during elbow flexion movement. The SMUAP of the MU01 was observed at (a) 10, (b) 15, (c) 20, and (d) 25 s. These results confirmed that our developed method continuously tracked the SMUAP waveform changes during elbow flexion movement.

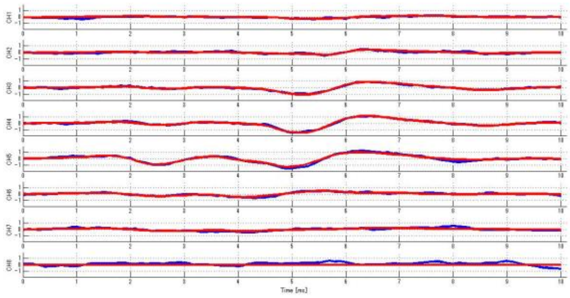

Figure 12: Decomposition process of the superimposed waveform.

Fig. 12 shows the result of the decomposition process for the superimposed waveform using the proposed method. The target was the signal of (iii) in Fig. 8. The blue line waveform is a measured SEMG, and the red line waveform is created by synthesizing the template of MU 01 and MU 02. The degree of coincidence of the waveforms was 73.93 %.

Fig. 13 shows the MUAPT in which the solid lines correspond to the elbow joint angle (the average velocity was approximately 5°/s); identified firings of the nine MUs are shown. Each bar represents one firing and firings of the same MUs are aligned horizontally. The average frequency of Motor Unit 01 (MU01) was 22.14 Hz and the standard deviation was 18.46 Hz. The average frequency of MU02 was 10.87 Hz, and the standard deviation was 6.20 Hz, and the average frequency of MU03 was 21.82 Hz, and the standard deviation was 7.18 Hz. MU01 and MU02 continued to fire for a relatively long period of time. The results of calculated MU's FRs agree with the generally accepted behavior of MU FRs.

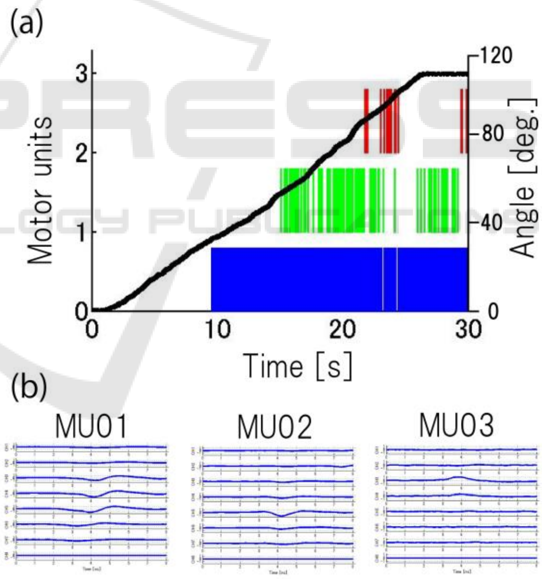

Figure 13: MUAP Train.

4 CONCLUSIONS

In physiology and medicine, methods to investigate the behavior of MUs are desired. We have developed an algorithm to decompose SMUAPs quantitatively during voluntary isovelocity elbow flexion. However, in some subjects whose fat tissue was thin, the shape of the SMUAP was most likely generated by a single MU and, as such, did not retain the same shape. For this reason, we modified our original SMUAP decomposition method to focus on tracking changes in the SMUAP waveform. The newly developed algorithm used a sequentially modified template matching method, based on superimposed SMUAPs, to calculate the FRs of MUs. Our results showed that the FRs were nearly the same as those cited in previous physiological studies. Thus, the algorithm proposed is expected to be useful for decomposing SMUAPs when the shape of SMUAPs are generated from a single MU and change with each firing.

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Numbers 26350678.

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