Development of Muscle Fatigue Scale-Based Biofeedback Device for Improving Muscle Endurance

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***Abstract*—This paper describes our developed biofeedback device based on Muscle Fatigue Scale (MFS). The device helps the senior to prevent injury and excessive burden while muscle training. At present, Japan faces the issues of population decrease and a super-aging society. Extension of healthy life expectancy and reduction of health disparities are especially the ultimate objectives that should be realized in Japan through the improvement of lifestyles and provision of a social environment. Seniors who want to remain healthy and active must prioritize doing regular physical activities. Also, avoiding excessive burden should be considered during exercise. Under the circumstances, we develop a biofeedback device based on MFS. Using the device, seniors as well as any other persons who train are able to do muscle training suitable for the condition of a muscle.**

***Index Terms*—biofeedback device, electromyogram, muscle fatigue**

I. Introduction

With the declining birthrate and the high aging population ratio, sufficient support cannot be provided to both care-receivers and caregivers due to an increase of the demands and the burden of medical expenses on the country. Advance in the aging of the population will be a large strain on the Japanese finances as it raises its expenditures on public pensions and items related to health insurance. Considering from the aspect, elderly people are required to have physical strength and walking ability to live as much as possible by themselves. However, elderly people's walking movement becomes inadequate because of muscle weakness with their aging. Therefore, the elderly people are required to work out properly to keep muscle strength in their daily lives. In this paper, in order to work out properly for the elderly people, we develop a biofeedback device based on MFS. Using the device, seniors can train their muscles suitable for the condition of a muscle.

II. Proper Muscle Training for the Elderly People

Skeletal muscles are roughly divided into fast-twitch muscle fiber (Type II muscle fibers) and slow-twitch muscle fiber (Type I muscle fibers). Type II muscle fibers can cause strong muscle contraction but has the low resistance fatigue and the short muscle duration. On the other hand, Type I muscle fibers shrink slowly, but has the high fatigue resistance and the long muscle endurance. Among two types of muscle fibers, resistance training for Type II muscle fibers is more effective for elderly people. However, the resistance training for the elderly people with lack of regular exercise, the training causes injuries and accidents in more cases than that for the healthy elderly people who exercise regularly.

For the elderly people who do not exercise regularly, proper training method is needed. Muscle fatigue, rather than muscle, should be monitored during the exercise. Besides, the training of the muscle endurance should be done by using the "Aerobic energy supply mechanism" which is a feature of the type I fiber energy supply mechanism. There are two types of this aerobic energy supply mechanism, "citric acid cycle" and "Electron transport chain." In particular, the tricarboxylic acid cycle (TCA cycle) is metabolic pathway of oxygen and "glucose," "amino acid," "fatty acid" Metabolic process to Generate energy (ATP). It is possible to create a body by improving the type I fiber that is not easily fatigued. In this way, the number of activities increase and thus, as a result, QOL can be improved.

Therefore, elderly people and people of obesity are controlling fatigue and making it possible to exercise for a long time, and it is possible to create a situation where fatty acids are easy to burn. It is thought that it can prevent the complications caused by obesity in the elderly and adults by exercise. Muscle fatigue is said to occur when muscle exertion cannot exert muscle power according to individual requirements. Muscle fatigue is classified into peripheral muscle fatigue and central muscle fatigue. In peripheral fatigue, it is affected by energy exhaustion, and it is mentioned that the performance of muscles decreases in the repetition of a short time. Central fatigue may be caused by a decrease in alpha motor neurons in the brain. The target of this study is to measure local muscle fatigue for peripheral fatigue in order to focus on muscle endurance [1].

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The characteristics of local muscle fatigue are said to cause fatigue when the concentration of glycogen depleted and the metabolite lactic acid rises above a certain level. There have been many analyses of local muscle fatigue to date. The estimation method of fatigue accumulation and recovery status is the comparison of performance test before and after exercise, urine test, blood test, exhalation gas, blood lactate concentration, and electromyogram comparison. Tests compare many of these tests before and after exercise, and most of them cannot be measured during exercise. Furthermore, muscle fatigue may be measured by methods such as lactic acid, blood oxygen saturation, muscle sound, and electromyography.

However, in the current measurement, it is general to analyze after the end of exercise without feedback in real time. Also, there is various frequency analysis as an analysis method of muscle fatigue of EMG. Methods include measuring superimposed M waves induced by electrical stimulation during regular voluntary contraction exercise, comparison of mean power (Mean Power Frequency: MPF) or Median power frequency (MF), measurement of muscle fiber conduction velocity, and the like [2]-[4]. Most of the general training equipment are devices based on the respiratory system such as treadmills and bicycle ergometers, and there is currently no training equipment based on muscle fatigue. This is because many studies using heartbeats that are easy to measure have been conducted because of measurement easiness. However, analysis methods for feedback in real time have not been established. Also, muscle fatigue measuring devices have been studied, but they have not been established as devices [5]-[7].

So, this study aims at “Development of biofeedback device for improvement of muscle endurance based on muscle fatigue.”

III. Biofeedback Device Based on MFS

Fig. 1 shows our developed biofeedback device based on MFS. We integrated the functionality into M5Stack, modular stackable product development toolkits based on ESP32. Fig. 2 shows usage of our proposed device. Myoelectric potential is detected by the electrode showed in Fig. 3 for electromyography measurement. After that, the myoelectric potential is amplified by the amplifier on the electromyography measurement the unit (sparkfun MyoWare Muscle Sensor SEN-13723) and input into the ESP32 on the M5Stack through A/D converter on the microchip. The signal converted by the A/D is processed through Fast Fourier Transformation (FFT). Then, the frequency spectrum is displayed on the screen as a bar chart. Since we need the frequency range from 20Hz to 400Hz, sampling rate is set to 800Hz. Considering the delay of calculation and the desired display update rate, we decided the number of samples for FFT as 256 samples. Fatigue scale is calculated based on the frequency and the intensity of the myoelectric potential. Smiley is displayed on the screen according to the fatigue scale to make it easier for recognizing the muscle fatigue. Fig. 4 shows variation of smiley corresponds to one of the fatigue scales, OMNI-RES scale [8]-[13].

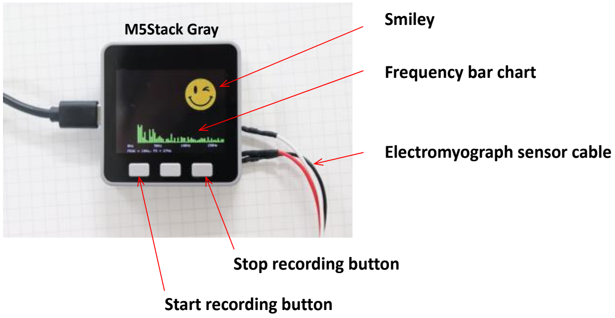

Figure 1. Muscle fatigue scale-based biofeedback device.

Figure 2. Electromyograph sensor (sparkfan MyoWare SEN-13723).

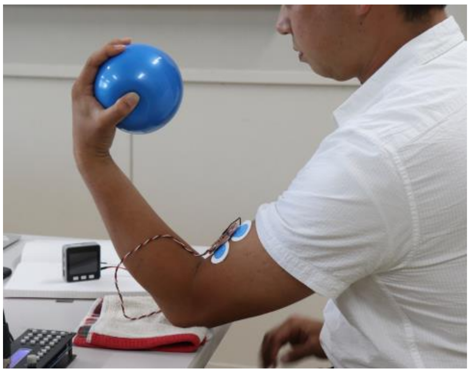

Figure 3. Muscle training using our proposed biofeedback device.

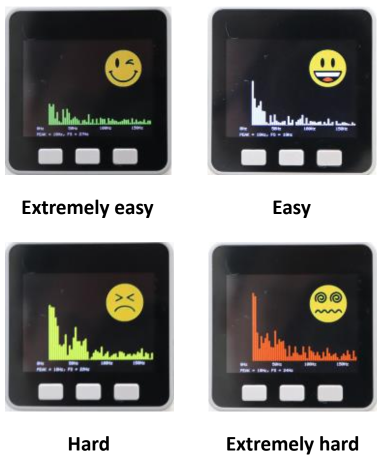

Figure 4. Variation of OMNI-RES scale displayed on the screen.

IV. Experiment

We conducted experiments in which muscle loads applied to a subject. Before the experiments, we explained the aim of the experiments to the subject and gained his approval. In addition, the experiment was aborted if the subject felt uncomfortable condition. The subject was a 18-year male, 187cm tall and 65kg weight. We measured Electromyogram (EMG), Rate of Perceived Exertion (RPE), and blood lactate concentration (ARKRAY Lactate Pro LT-1710).

The experiment is conducted along the following procedure:

1. Measurement of blood lactate concentration after 5-minute rest. The blood lactate concentration was measured by sampling the blood from a fingertip with a lancet needle.
2. Measurement of electromyograph during working out. An electromyograph sensor was stuck on a belly of biceps brachii.
3. Report of RPE every one minute during working out so as to confirm the muscle state.
4. Measurement of blood lactate concentration every 5 minutes during working out.

A 3kg medicine ball was utilized as an exercise load. 2-minute bending and 2-minute stretching of a brachium was conducted in a state of an elbow fixed. The subject kept time with a metronome. The experiment was ended when the subject cannot move his brachium.

V. Mean Power Frequency

Frequency analysis of the electromyographic data was executed to obtain Mean Power Frequency (MPF). At this time, sampling frequency of the electromyograph was 800Hz, and FFT was processed using 256 points of electromyograph. Therefore, MPF is obtained every 0.32s theoretically. However, we measured and realized the actual time was 0.37s. We calculated MPF per minute from 162 MPFs obtained every 0.37s.

VI. Experimental Results

Fig. 5 shows time series of blood lactate concentration and RPE. The RPE was not changed in the first 15 minutes. During the time, the lactate concentration slightly decreased. After 15 minutes, the RPE and the lactate concentration increased gradually. Fig. 6 shows time series of the lactate concentration and MPF per one minute. They were almost not changed, however, after 5 minutes, the MPF had a decreasing trend.

VII. Discussion

Reasons of the decreasing trend of the MPF are (1) synchronization of a Motor Unit (MU), (2) increasing and decreasing of motorization of the MU, (3) Type II muscle, involved in high frequency, becomes unmovable faster than Type I muscle, and (4) reduction of transmitting speed on the muscle fiber.

Regarding the MU, each muscle fiber is dominated by one motor neuron, however, each motor neuron nervously dominates several muscle fibers. The number of muscle fibers nervously dominated by one motor neuron varies depending on a kind of muscle. As for a major muscle such as a quadriceps femoris muscle, hundreds of muscle fibers are nervously dominated by one motor neuron. In addition, the muscles do not always contract all fibers, but a part of fibers if it need not strong power. The muscles put out of action by muscle fatigue. But not all muscle fibers become unable to contract at one time. Each MU gradually lose its ability to contract muscles. Especially, Type II fibers (fast muscles) regarding the high frequency get tired faster than Type I fibers (slow muscle) since Type II fibers have low fatigue tolerance. On the other hand, since Type I fibers, involved with the low frequency, have high fatigue tolerance, it could continue to contract muscles, therefore the MFP shifted to the low frequency side. According to the above results, we realized our developed device could measure the muscle fatigue state.

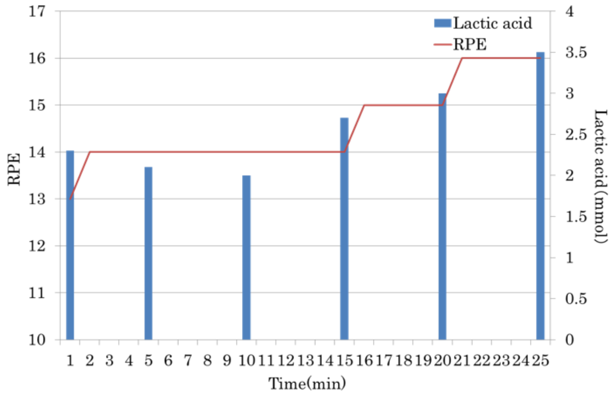

Figure 5. Relationship between lactate acid and rating of perceived exertion during exercise time.

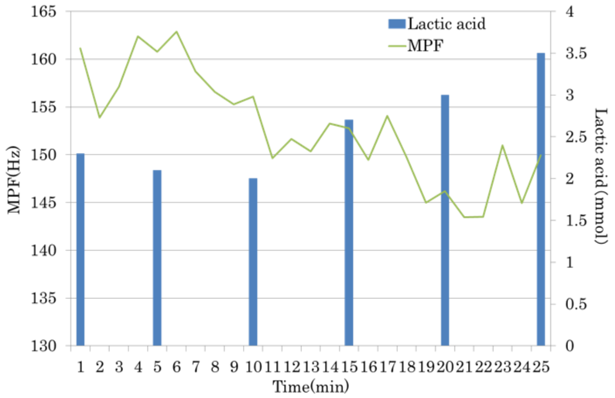

Figure 6. Relationship between lactate acid and mean power frequency during exercise time.

VIII. Conclusions

In this study, we developed a device to estimate muscle fatigue and to perform biofeedback, which enabled to measure muscle fatigue in real time using EMG. The device also enabled frequency analysis of the electromyographic data for acquiring the Mean Power Frequency (MPF). According to our muscle fatigue experiment, we realized that MPF decreased with the muscle fatigue and the lactate concentration is synchronized with the RPE. These experimental results imply our proposed method will provide the muscle fatigue level which is useful information for improvement of muscle endurance without any injury. For the future, we will increase the number of subjects in order to increase the accuracy of our proposed device.

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