35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Evaluation of the effectiveness of muscle assistive device using muscle fatigue analysis

Youngjin Lee, Youngjoon Chee

***Abstract*— There have been many kinds of wearable robots or wearable assistive devices to reduce the burden of workers in several industries. But there is no quantitative and objective method to evaluate the effectiveness of the device. In this study, a new method to evaluate the effectiveness of the muscle assistive device is suggested.**

5 male subjects attended in the experiment to maintain posture of the overhead welding task with the tools. The surface electromyogram (sEMG) was recorded on 6 muscles with and without wearing the assistive device. The mean frequency (MNF) and root mean square (RMS) were calculated and analyzed to evaluate the fatigue level of each muscle. The modified Borg RPE scale was scored in every minute for comparison through the experiment.

By comparing the MNF and RMS values when wearing assistive device and not wearing assistive device, we can specify the device can reduce the fatigue in some muscles. The slopes of regression line of MNF and RMS plots may represent the fatigue level of each muscle, which can be used to evaluate the effect of the assistive device.

I. Introduction

In spite of the modern technologies, still there are a lot of tasks in construction fields and other heavy industries. When the workload is over the limit of the worker, musculoskeletal disease may happen and sometimes it is the reason of an accident [1]. In order to solve these problems, the wearable robots and simple assistive devices are suggested. These are expected to prevent the musculoskeletal disorders and accidents. Also the work efficiency may be increased. To find the optimal design of these devices, we need the objective and specific method to evaluate the effectiveness of this assistive device. There have been demands for objective assessment of physical workload in ergonomics aspects such as the design of common work.

There are three types for the objective assessment of physical workload; questionnaire responses methods and biomechanical methods, physiological methods [2]. Questionnaire responses methods are the subjective evaluation of the subject. Borg scale is well known and is used widely used in many studies [3]. This method is useful the evaluation of one subject for various works. But criteria of evaluation are subjective to each subject. So the score of one subject may have different meaning from the score of other subject.

In biomechanical methods, video analysis and surface electromyography (sEMG) are widely used. EMG is the signal from muscle contraction and it is used in clinics. There have been many studies about sEMG to use in muscle fatigue analysis and workload analysis [4-5]. EMG has been applied in a variety of fields such as medicine, rehabilitation, ergonomics et al [5]. It has advantages of non-invasiveness, low cost, and ease of use. On the same time, the consistency of the measurement condition and inter-subject variability are known as the limitation of EMG analysis. It is known that the amplitude of the EMG signal increases and the central frequency in power spectrum of EMG decreases when the fatigue of muscle increases [6-7]. Based on these properties, there is a study that the fatigue analysis of muscle using mechanomyogram and electromyogram according to change of shoulder and Elbow postures and change of percents of maximal voluntary contraction [8].

Figure 1. Muscle assistive device for overhead welding

In physiological methods, the heart rate, oxygen consumption, carbon dioxide emissions of subject are used to evaluate the physical workload [9]. Even though the values of them are reliable, it is not convenient to wear the mask for respiration analysis. Also we can't specify which part of the body gets fatigue because it gives the value of whole body.

The goal of this study is to suggest the quantitative evaluation method using sEMG. With this evaluation method, we hope to analyze the effectiveness of the muscle assistive device. The assistive device in this study supports the neck, arms, back while holding the welding tool at overhead welding task posture that is used in the industrial fields many times as shown in Fig. 1. By comparing parameters from EMG

Y. Lee is with the Department Biomedical Engineering, University of Ulsan, Ulsan, South Korea (e-mail: paydfdf@gmail.com)

Y. Chee is with the Department Biomedical Engineering, University of Ulsan, Ulsan, South Korea (Phone: +82-52-259-1307; fax: +82-52-259-1306; e-mail: yjchee@ulsan.ac.kr)

978-1-4577-0216-7/13/$26.00 ©2013 IEEE

signals when this device assists and not, we tried to understand the device makes less fatigue or not.

II. METHODS

A. Subjects and experimental procedures

Five young healthy male subjects participated in this experiment. The mean (SD) of age, height, and body weight were 26.8 years (9.0), 174.0 cm (4.1), 64.4 kg (1.8), respectively. The posture of overhead welding is shown in Fig. 2 (a). Based on the special requirement of welding process, the worker should hold on the gun for 10 minutes or longer with his protection mask. The target point of welding was 190 cm height. The subjects were requested to imitate this posture.

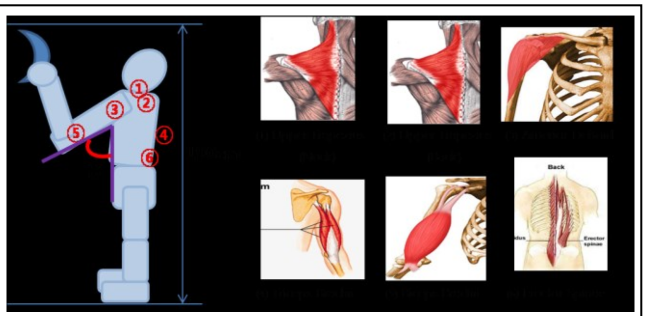
We selected five muscles to keep this posture with preliminary experiment; upper trapezius (neck), upper trapezius (back), anterior deltoid, triceps brachii, biceps brachii, erector spinae. Fig. 3 shows these muscles.

Figure 2. Posture of overhead welding task in this experiment (a) without assistive device (b) with assistive device

(a) (b)

After attaching the electrodes on each muscle, the subject was told to keep the posture as long as possible. In this session, the subject doesn't wear the assistive device. In every minute, the subject is asked to say the workload as Borg RPE scale. Table 1 shows the Borg RPE scale that we used. When the subject gives up to maintain the posture any more, the first experiment is finished. Just before finishing first experiment, the subject reported Borg RPE score as 20.

Figure 3. Selected muscle in this experiment



After 6 hour rest, the second experiment was started. In the second experiment, the subject wears the muscle assistive device as shown in Fig. 2 (b). In this session, we set 15 minutes as limit.

EMG measurement was done during the experiment. EMG amplifier and wireless transmitter (BioRadio 150, Cleveland Medical Devices, USA) was used to record 6 channel EMG data. 3~200Hz band-pass filter and 60Hz notch filter were used. Signal was sampled at 960Hz.

TABLE Ⅰ. Borg RPE scale

Borg RPE Scale	
Rating	***Description***
6	Nothing at all
7	Very, very light
8	-
9	Very light
10	-
11	Fairly light
12	-
13	Somewhat hard
14	-
15	Hard
16	-
17	Very hard
18	-
19	Very, very hard
20	Limitation

B. Data analysis

To extract parameters of the muscle fatigue from sEMG signals, root mean square (RMS) of 5 seconds segment of sEMG in every 20 seconds was calculated with equation (1). x_i is the sEMG value in mV for one muscle and n is the number of data of sEMG signals.

$$M_{RMS} = \sqrt{\frac{\sum x_i^2}{n}} \quad (1)$$

According to the many report, RMS increases according to the fatigue level. Another property of sEMG on fatigue, central frequency decreases according the fatigue level. To parameterize this property, we calculate mean frequency (MNF) of sEMG data using the equation (2). For each segment of 20 seconds, power spectrum is calculated and we could calculate MNF.

$$f_{mean} = \frac{\int_0^{\pi} \omega S_x(e^{j\omega}) d\omega}{\int_0^{\pi} S_x(e^{j\omega}) d\omega} \quad (2)$$

ω is frequency and S_x is power spectrum. In other words, MNF is value which is obtained by dividing the total power spectrum by summing the multiply of the size of power spectrum of each frequency [9-10]. All the calculation was done with MATLAB.

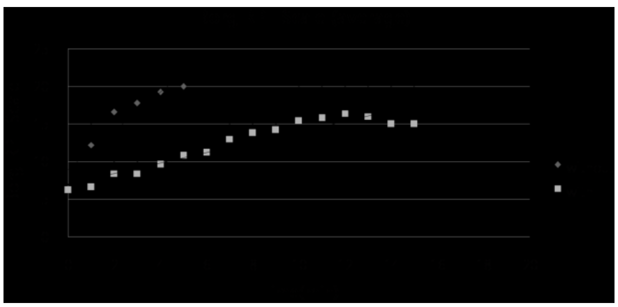
Because there are many variables in EMG recording like site of electrode, firm attachment, and inter-subject variability, they normalize its value with maximal voluntary contraction (MVC) of each muscle. In this experiment, we are interested in the fatigue level changes according to time. So we plotted the RMS and MNF with time, and calculate the scope of regression line. When his fatigue level increases fast, the slope might be steep. We evaluated the degree of muscle fatigue according to size of gradient and checked with Borg RPE score when possible.

III. RESULTS

A. Borg RPE Scale

Fig. 4 shows the mean and SD of Borg RPE scale for 5 subjects. The blue diamond is the score when the subject doesn't wear the assistive device (hereinafter we will call as 'without'). All of the subjects could keep the posture for 5 minutes in minimum. Most of the subjects arrived at 20 which mean the limitation of maintaining the posture. The red square is the data when the subject wears the assistive device (hereinafter we will call as 'with'). All of the participants could keep more than 15 minutes and we stopped the measurement. We could see the SD increases according to time. This reflects each subject feels the fatigue subjectively. But there is distinct trend according to time and fatigue.

Figure 4. The mean(SD vertical bar) of Borg RPE scale. The blue diamond (without) is the score when the subject doesn't wear the assistive device. The red square is the score when the subject wears the assistive device (with)

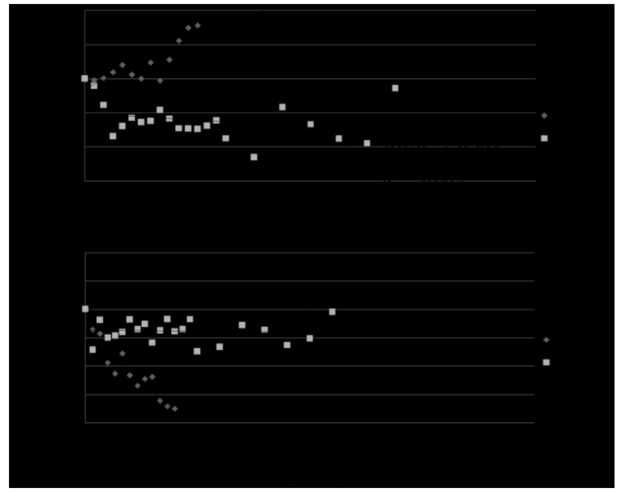


B. Fatigue analysis of sEMG

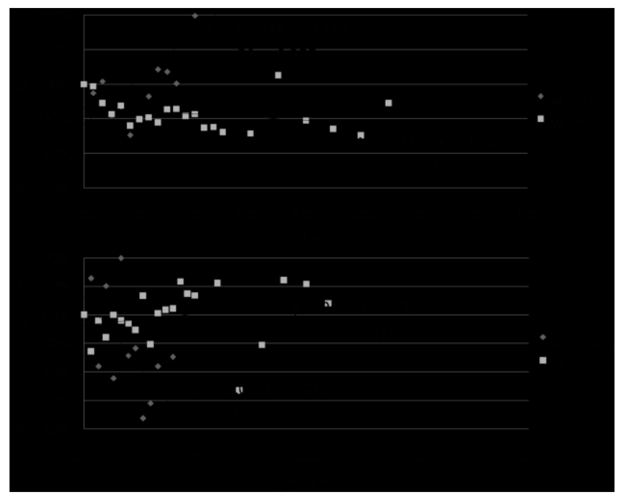
The results of one subject of sEMG fatigue analysis are shown in Fig. 5. The top plot of Fig. 5 (a) is for RMS changes in anterior deltoid when he wears the assistive device ('with', blues diamond) and without ('without', red square). The linear regression curve was also shown. As prescribed previously, the slope in 'without' is high. In 'with' condition, the rising is small and sometimes the slope is negative. Also the data is scattered from case to case. The slope as the proposed index for muscle workload is not sensitive in light effort. The bottom plot of Fig. 5 (a). shows the MNF changes in anterior deltoid for 'with' and 'without' condition. Also the slope of MNF in 'without' is high in decreasing direction. The decreasing in 'with' condition is smaller than that in 'without' condition. This phenomenon is similar with Borg RPE scale.

Fig. 5 (b) shows the result for triceps brachii of one subject in 'with' and 'without' condition. The trend of the plot is similar with Fig. 5 (a). Fig. 5 (c) shows the result for biceps brachii of the subject in 'with' and 'without' condition. This result is quite different from those of triceps brachii. There are two reasons we can consider. One is that this part of the body does not play so important role for overhead welding posture when the slope in 'without' is not so high. If the slope in 'without' is very high and slope in 'with' is not high, the assistive device was effective so the fatigue on the muscle decreased a lot.

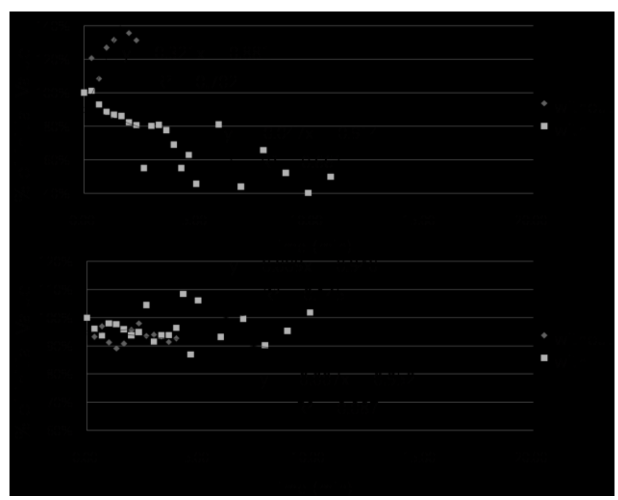
Figure 5. RMS and MNF changes in 'with' and 'without' condition. The top plot is for RMS and bottom plot is for MNF. (a) Anterior deltoid, (b) Triceps brachii, (c) Biceps brachii



(a)



(b)



(c)

Fig. 6 shows the mean of slope for 5 muscles in ‘with’ and ‘without’ condition. According to Fig. 6 (a) RMS, except erectus spinae, all the five muscles get fatigue based on the slope in ‘without’ condition. In ‘with’ condition, all the five muscles get small or no fatigue. As stated previously, the slope of small value means light work, and it is not meaningful whether the polarity is positive or negative. We can interpret that the erectus spinae plays small role in this posture, and the assistive device is effective in five muscles. Especially the effect was high in triceps brachii and biceps brachii. and MBF plot.

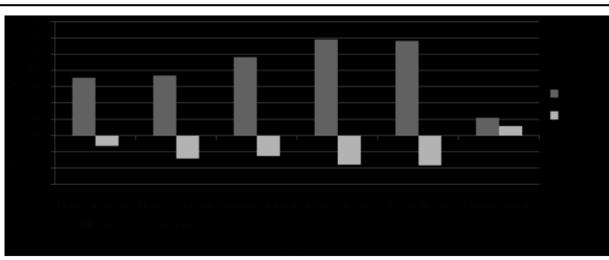
Fig. 6 (b) shows the mean of slope in MNF plot. The differences between ‘with’ and ‘without’ is higher than those in RMS. The interpretation is same except for the triceps brachii. We could not figure out the reason. One of the limitations of this analysis is the SD of RMS and MNF is high and scattered a lot.

In ‘with’ condition, the correlation coefficients between Borg RPE scale and RMS was not significant in all muscles. But, in ‘without’ condition, the correlation coefficients between Borg RPE scale and RMS was significant in upper trapezius (neck), upper trapezius (back), triceps brachii and biceps brachii. RMS can’t measure the muscle fatigue in low fatigue changes. But, RMS can measure the muscle fatigue in high fatigue changes.

IV. Discussion and Conclusions

To find the optimal design of wearable robot and assistive device, we need the quantitative method to evaluate the device for each muscle. The goal of this study is to suggest the evaluation method using sEMG fatigue analysis. By comparing the slope in RMS (MNF) changes according to time between ‘with’ and ‘without’ condition, we could specify that which muscles were reduced with the assistive device in quantitative way. The steep slope (positive in RMS and negative in MNF) means high fatigue level. Because it is not sensitive in low level of workload and fatigue, the slope analysis is not meaningful.

Figure 6. The mean of slope for 5 muscles in ‘with’ and ‘without’ condition. (a) mean slope of RMS, (b) mean slope of MNF



(a)

(b)

The need for assistive device comes from the muscle fatigue. Muscle fatigue is related with the maintaining the posture for long time. With the assistive device in this experiment, the subject can use other muscles when some muscles get fatigue while maintaining the posture. Our method can evaluate the effect of this mechanism works effectively.

There are few limitations in this experiment. Before extracting RMS and MNF parameters, the data should be averaged in proper way. We didn’t do this in this study so the deviation of RMS and MNF value in plot were so high and there are some outliers which make big errors in regression. To validate the effectiveness of slope parameter as fatigue index, the statistical analysis for Fig. 6 should be performed. It is the simple mean of RMS and MNF for 5 subjects. Also all the limitations related with EMG analysis should be considered in this study.

As conclusion, by comparing the NMF and RMS values between wearing assistive devices and wearing no device, we can specify the device can reduce the fatigue in specific muscles. The slope of regression line of MNF and RMS time plot may represent the fatigue level of time of each muscle, which can be used to evaluate the effect of the assistive device.

References

[1] S.Y. Jung, J.W Gang and J.W Koo, “The relationship between grip strength and ground reaction force by change of position when lifting tasks,” Journal of the Ergonomics Society of Korea., vol. 28, no. 3 pp.41-47, 2009.

[2] J.Y Kim, J.S Park and Y.J Cho, “Biomechanical Measuring Techniques for Evaluation of Workload,” Journal of the Ergonomics Society of Korea, vol. 29, no. 4, pp. 445-453, 2010.

[3] G. A. Borg, "Psychophysical bases of perceived exertion," Med. Sci. Sports Exerc., vol. 14, pp. 377-381, 1982.

[4] T. Öberg, "Muscle fatigue and calibration of EMG measurements," Journal of Electromyography and Kinesiology, vol. 5, pp. 239-243, 1995.

[5] P. Konrad, "The abc of emg," A Practical Introduction to Kinesiological Electromyography, vol. 1, 2005.

[6] C. J. De Luca, "The use of surface electromyography in biomechanics," Journal of Applied Biomechanics, vol. 13, pp. 135-163, 1997.

[7] M. Cifrek, V. Medved, S. Tonkovic and S. Ostojic, "Surface EMG based muscle fatigue evaluation in biomechanics," Clin. Biomech. (Bristol, Avon), vol. 24, pp. 327-340, May, 2009.

[8] N. K. Mamaghani, Y. Shimomura, K. Iwanaga and T. Katsuura, "Mechanomyogram and electromyogram responses of upper limb during sustained isometric fatigue with varying shoulder and elbow postures." J. Physiol. Anthropol. Appl. Human Sci., vol. 21, pp. 29-43, 2002.

[9] J.S Park, H.K Kim and J.Y Choi, “Comparison Analysis of Physiological Work Capacity for Different Tasks,” Journal of the Ergonomics society of Korea, vol. 15, no. 2, 1996.

[10] L. Sörnmo and P. Laguna, Bioelectrical Signal Processing in Cardiac and Neurological Applications. Academic Press, 2005, pp. 337-364