A Prediction Method of Muscle Force Using sEMG

Gang Li, Haifeng Chen, Jungtae Lee
Department of Computer Science and Engineering
Pusan National University
Busan, Republic of Korea
lixiaogang110217@hotmail.com, {chenhaifeng, jtlee}@pusan.ac.kr

***Abstract*—Surface electromyography (sEMG) technology is used to record and display the electrical activities of human muscles, by which researchers are able to make a muscle force evaluation. In this study, in order to accurately feedback the information about athletes' forearm force training, the Maximum Voluntary Contraction (MVC) is proved as the indicator of maximum forearm muscle force by developing a winner prediction method of arm wrestling game. Experiment results based on healthy 12 volunteers' (all males, average age is 25±3) are reported in this paper. The results show that the prediction method can be accurately performed so as to estimate who is the winner.**

Keywords-surface electromyography, sEMG signal processing, MVC, arm wrestling, athletes' force training

I. INTRODUCTION

The moment-to-moment control of muscle force by the nervous system is accomplished by electrical signals that are sent from motor neurons to muscle fibers. These signals, which are known as action potentials, can be recorded as they propagate along the sarcolemma of muscle fibers, from the neuromuscular junction to the ends of the fibers. Such a recording is referred to as an electromyogram (EMG). If the EMG signals are recorded through the electrodes placed on the skin over a muscle, the technology is called surface electromyogram (sEMG) [1].

In the past two decades, many studies of muscle force evaluation via sEMG had been performed. Peter Konrad had concluded that EMG activation is the preliminary condition for any force development and one can expect a very close relationship between both measures [2]. Blacksburg and Virginia had performed an experiment and pointed out many muscles seem to exhibit a linear relationship between force and sEMG [3]. Unfortunately, today there is still not an authoritative definition on the relationship between muscle force and sEMG.

Actually, if we focus on the muscle's Maximum Voluntary Contraction (MVC), we could find that the relationship between muscle force and MVC is more meaningful and practical, especially in the activities of athletes' muscle force training. If we can prove that MVC value acquired via sEMG acquisition system is the indictor of maximum muscle force, then those athletes are able to obtain accurate feedback information about their force training. According to the MVC value, not only can athletes learn their training effect and make next training plan, but also they are able to know the situation of single muscle because of the precious positioning of the electrodes, rather than mixed effect produced by multiple muscles via mechanical force measuring device, such as dynamometer and hand-muscle developer.

The MVC refers to muscle's maximum voluntary contraction which is performed against static resistance. Essentially, MVC is muscle's isometric contractions, differing only in to what degree muscle may contract. Isometric contractions occur in our body when the force of isometric contraction is needed to stop a body part from moving. When an isometric contraction acts to hold a body part in position, that body part is said to be fixed or stabilized [4]. And that is why we choose arm-wrestling as the practical method to check validity of MVC value as the indicator of the maximum muscle force. When person arm wrestles with another individual, in this case the muscle's contraction is isometric contraction, hence neither force is capable of moving a body part, and the part remains statically still. However it is just short-term isometric contraction. Soon, the bigger MVC value one breaks the balance and at that moment the winner appears.

In this study, we firstly illustrated the main functional muscles in arm-wrestling and obtained the MVC value of that. According to different roles of different muscle, we also developed and implemented a prediction method, based on MVC value and statistic t-test, to estimate the gamer winner. Secondly, actual arm-wrestling games were performed to validate the predicted experiment results. If the prediction method can work well, undoubtedly, the MVC value will be proved it is the indicator of muscle's maximum force. The greater the MVC value, the greater the muscle force of people. Fig.1 shows the framework of the experiment.

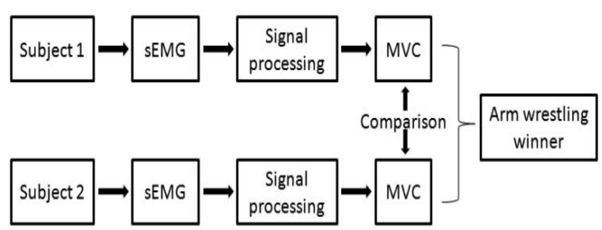


Figure 1. Framework of experiment system

978-0-7695-3653-8/09 $25.00 © 2009 IEEE
DOI 10.1109/IACSIT-SC.2009.11

II. METHODS

A. Target muscles

Arm-wrestling is a funny and simple sport. In a very short period, the game winner will be decided. This is another important reason to choose it as the method to investigate whether MVC value can accurately reflect the level of maximum muscle force.

As the main functional muscles in this sport, the brachialis is charge of fixing arm part in place and the triceps brachii is responsible for force output [5]–[7]. In another word, under the same force level of brachialis, the triceps brachii plays a determinant role. Therefore, we decided to target the two muscles and obtain MVC values from them respectively.

B. Materials and subjects

The electrodes applied were disposable bipolar ones with 2cm in diameter, and an inter-electrode spacing of 2cm. It is significant to make two wires of one pair electrodes as closely as possible if want to change unipolar into bipolar ones by hand, lessening the power line interference at large.

12 volunteers, all males whose average age 25±3, are from healthy undergraduates of department of computer science. The dominant arm of each one among them is right arm.

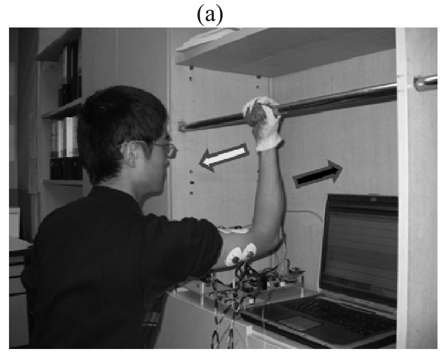
C. Procedure

Records of sEMG signals of both the brachialis and triceps brachii were used to evaluate muscle force. The skin over target muscles was cleaned with 70% alcohol and attached to electrodes without hydrophilic gel electrolyte. Authors followed the localization, orientation for placing the electrodes suggested by the European Recommendation for Surface Electromyography of the SENIAM project [8]. The reference electrode was placed away as far as possible, and a bony prominence is recommended. We chose the subjects' right elbows.

Subjects of this study were paired into six groups randomly. Each group was composed of two subjects. In order to get a more stable reference brachialis and triceps brachii MVC value of the dominant arm, subjects were arranged in a seated position to output their maximum force, which is called MVC test circle. To get better effect, subjects were required to keep a 90° position between arm and forearm [2], as shown in Fig.2. The MVC test circle, which has a 6-second duration, was performed 5 times for each subject, every time at 20-minute intervals. Consequently, author obtained 5 measurements for each muscle. Must be noted is that all the subjects were required to output their maximum force gradually within 6 seconds and maintain it 2 seconds and then decline within 2 seconds respectively, avoiding displacement of electrodes caused by fast contraction and relaxation. All experiment arrangements were shown in Fig.3.

After MVC tests all subjects were asked to rest 30 minutes, and then two subjects of each group performed arm-wrestling game using their dominant arms so as to know who the real winner is. Must be noted is that all subjects were required a ban on any wrestling skills or tips, such as wresting the wrists, which can prevent them from beating partners who only depended on the muscles we focused on. The playtime of arm wrestling was set as 8 seconds which is consistent with the experiment schedule. If no winner within 8 seconds, game would end in a tie.

(a)



(b)

Figure 2. Proposals for MVC values test circles of triceps brachii (a) and brachialis (b) respectively. The white thin arrow indicates movement direction, the black thick arrows the resistance direction.

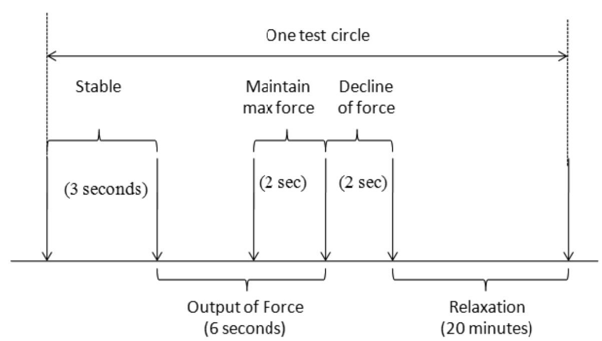


Figure 3. Schedule for experiment

D. sEMG recording

sEMG was recorded using a 4-channel sEMG acquisition system. The electrodes were attached on both the brachialis and triceps brachii muscle regions. The sEMG was continuously recorded and amplified at sampling rate 1200Hz, with a 20-500Hz band-pass filter and 60Hz power line interference adaptive filter. Fig.4 shows the received 3 seconds stable sEMG signals from brachialis with peak-to-peak amplitude of 80uV. Fig.5 demonstrates the

MVC sEMG signals from brachialis with 2.5mV (peak-to-peak). The Fig.6 displays the sEMG signals under force-declining condition, to which shifting from MVC force-outputting situation.

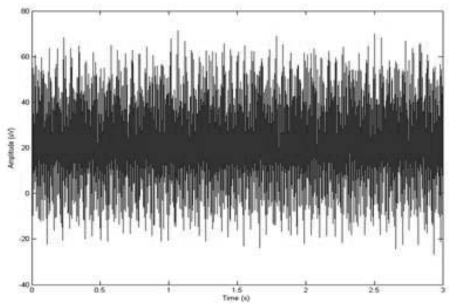


Figure. 4. Received 3 seconds stable sEMG signals

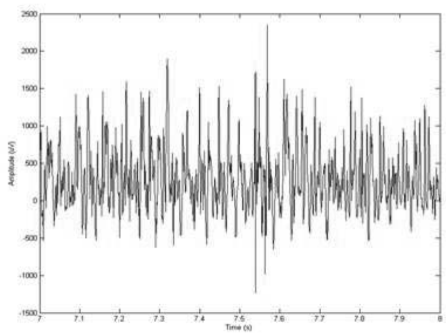


Figure 5. Received 1 second force-outputting sEMG signals

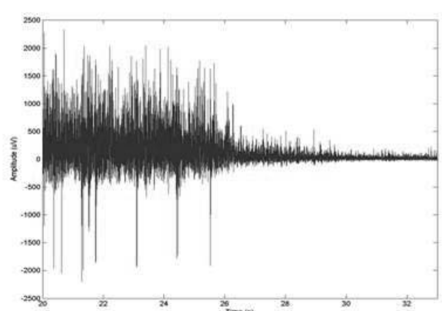


Figure 6. Received 12 seconds force-declining sEMG signals

E. Analysis

Raw sEMG data of each group was normalized by calculating the root-mean-square (RMS) over MVC test circle and then figured out the MVC values which were not calculated as a single peak data point. A more stable reference MVC value is the mean amplitude of the highest signal portion, of which the duration is determined by the maintain time of maximum force. In experiment, we required subjects to maintain 2 seconds, otherwise longer time will lead to fatigue, to which we have been pushing for putting a stop.

The t-test was used to determine if there is a significant distinction of MVC force between two subjects of each group. The level of significance was set at p=0.05.

Given 12 individuals we have 66 different ways to choose a pair. In another word, each subject should have competed against all the other ones, and in several arm-wrestling sessions. In this study, we regulated it is a best of three game, thus each group performed 3 arm-wrestling sessions.

For each group, if records of brachialis exists obvious MVC force distinction, then calculate mean MVC values of the 5 measurements. The higher mean value is regarded as game winner. Otherwise, if there is no obvious distinction in brachialis but in triceps brachii, then figure out mean MVC values of 5 measurements of triceps brachii. Who has a higher mean value is estimated as winner. While if neither brachialis nor triceps brachii exists obvious distinction determined by t-test way, it is considered that this game session is drawn. Fig.7 shows the specific winner prediction method.

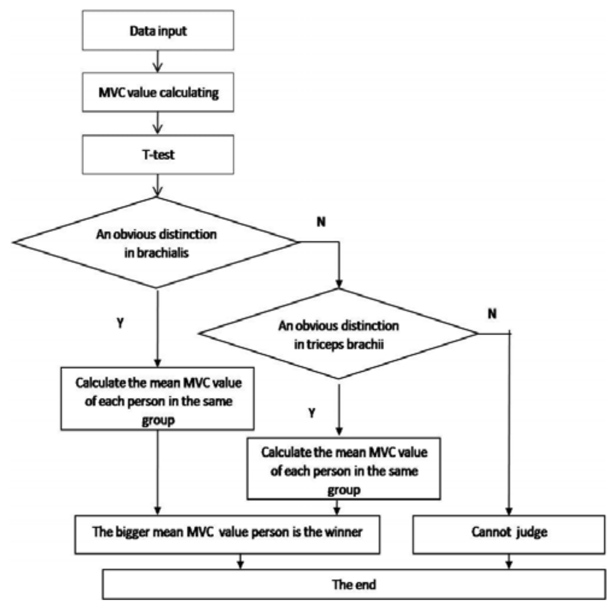


Figure 7. Winner prediction method

III. RESULTS

The 66 experiment results were divided into 3 different types as shown in table 1. We name the first one triceps-dominant type which was consisted of 38 groups. The term “triceps-dominant” means that two subjects in certain group were the same level of muscle force in brachialis while obvious distinction of force output in triceps brachii. The second type, approximately 40% of total experiment results, is called brachialis-dominant type, characterized by significant force level in brachialis. We call the last one unrecognizable type, indicating no winner in this group and also accounting for the smallest percentage of total three types, as shown in Fig.8.

Table 1: Experiment results (Parameters of t-test: p=0.05, n=5, t=2.7764; E-winner: Estimated winner, A-winner: Actual winner, "●" : Winner, "——" : Empty)

Group#	Subject#	MVC Value				E-winner	A-winner
		Brachialis		*Triceps brachii*			
		T value	*Mean (mV)*	*T value*	*Mean (mV)*		
1	1	0.055426	——	7.425018	0.67		
	2		——		1.15	●	●
5	9	8.102167	2.00	——	——	●	●
	10		1.31		——		
27	6	0.730333	——	0.240133	——	——	——
	9		——		——		

From the data of group #1, we can clearly see that no obvious distinction occurred in the MVC force of brachialis between two subjects, which were determined by t-test result (t-value) that is just 0.055426, less than t (2.7764). According to the winner prediction method, we had to perform t-test for triceps brachii, result of which indicates that there was apparent difference of MVC force in triceps brachii between two subjects. Finally, we can predict subject #2 was the winner in terms of mean MVC value. However, group #5 is slightly simple to analysis because obvious distinction existed in the MVC force of brachialis, which was determined by t value that is up to 8.102167, being higher than t. Thus, we can directly estimate winner as subject #3. Group #27 is quiet impressive because there was no winner in the game as neither brachialis nor triceps brachii existed obvious difference of MVC values between two subjects. At that time, two subjects couldn't beat each other and 8 seconds later game ended in a tie.

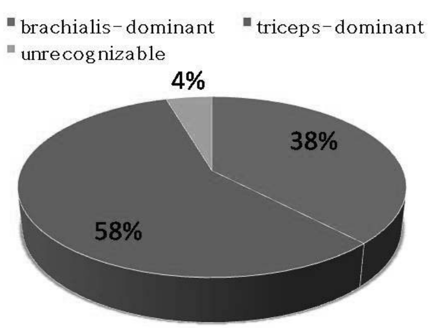


Figure 8. Three types of experiment results

All 66 inferences were consistent with the actual results, indicating the validity of MVC value for reflecting maximum muscle force.

IV. Discussion

In order to enable athletes to obtain more accurate training results of force activities, we studied the relationship between MVC value and muscle force. A winner prediction method for arm wrestling game had also been proposed and implemented. A large number of experimental results show that arm-wrestling is a credible and funny method to check the validity of MVC value which is the indicator of maximum muscle force.

To our knowledge, high-tech means in sports training increasingly play an important role. In Europe, for example, in the aspect of on-the-spot commanding in the volleyball match, coaches can analyze opponents' varied ball route and fast-changing tactics, according to real-time data from computer system. Similarly, if we can integrate sEMG technology into athletes' force exercises, in the field of non-on-the-spot, training will be more scientific.

In the past, if certain athlete had been defeated in arm-wrestling or other sports, he would determine to make more efforts to force training. His enterprise deserves praise, however blind effort is in vain because the athlete has no way of knowing why he failed and which muscle is stronger or weaker than opponent. Now, through electrodes' positioning of sEMG technology and prediction method, athletes are able to learn clearly why they failed or successed. Next, they can make highly personal and targeted training programs.

Additionally, for the coaches, they can know the overall muscle force situation of team members in terms of the pie charts that show the different percentage of all athletes' training results that something like Fig.8.

In theory, those athletes may effectively improve their force training plans through feedback from MVC value. However, current market-oriented sEMG devices take up a lot of room because of the monitoring and signal process via PC. In addition, the surface electrodes and sEMG system is not all-in-one. Next, we are planning to develop a more flexible sEMG acquisition device which is a wireless embedded and electrodes-device-integration sEMG system. In this case, it is more convenient to measure athletes anywhere.

References

[1] Roger M. Enoka, "Neuromechanics of Human Movement (Third Edition)," Human Kinetics Press, pp. 46-56, 2002

[2] Peter Konrad, "The ABC of EMG," in A Practical Introduction to Kinesiological Electromyography Version 1.0, Noraxon INC, USA, pp.26-43, 2005

[3] Blacksburg, Virginia, "Finger force capability: measurement and prediction using anthropometric and myoelectric measures," *IEEE/ICME International Conference on Complex Medical Engineering*, 1229-34, 2007

[4] Peter Konrad, "The ABC of EMG," in A Practical Introduction to Kinesiological Electromyography Version 1.0, Noraxon INC, USA, pp.26-43, 2005

[5] Blacksburg, Virginia, "Finger force capability: measurement and prediction using anthropometric and myoelectric measures," *IEEE/ICME International Conference on Complex Medical Engineering*, 1229-34, 2007

[6] Joseph E. Muscolino, "Kinesiology (The Skeletal System and Muscle Function," Mosby Elsevier Press, 2006

[7] Hefei, "The Design and Implementation of Arm Wrestling Robot," June 2006, *Proceedings of the 6th World Congress on Intelligent Control and Automation*, China, 8829-32, 2006

[8] 1st version, Brachialis Exercise, *http://www.eiyc.com /brachialis.htm*

[9] 1st version, Heavy Bench Press Partials in a Power Rack for Powerful Triceps brachii, *http://www.eiyc.com /tip16.htm*

[10] D.F.Stegeman, H.J.Hermens, "Standards for surface electromyography: the European project'Surface EMG for non-invasive assessment of muscles (SENIAM)'" pp 109-111