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Hand Grip-EMG Muscle Response

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One of the most important factors in hand-arm system research is the information about hand grip force and pressing force on a tool handle. This article focuses on an alternative method to measure grip force. For grip force, one of the most popular solutions is a special handle with force sensors. However, when we want to use it with regular hand tool like e.g. a drill, it seems to be uncomfortable because we must interfere in handle construction. A solution proposed in this article is based on technique for evaluating and recording the electrical activity produced by muscles, electromyography (EMG). It has been assumed that EMG signal will be proportional to muscle tension responsible for palm grip. This solution have one significant advantage when comparing to special handle. It can be used with regular tool without interfering in the handle. Measurement presented in this article have been carried out with use of surface electromyography (sEMG). It is not invasive method which enables to measure EMG signal through placing stickers with electrodes directly on a skin.

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1. Introduction

The fact that EMG signal is useful for evaluating muscles activity has been confirmed in many publications before [1–3].

A research presented in this article is a part of a project in which we want to determine the grip force with using EMG signal as a factor responsible for hand-arm muscles activity. As every human being is an individuality, the system must be calibrated each time.

In this article we have focused on determining the most advantageous points on forearm that can be used to place EMG electrodes. On the basis of publications available it can be stated that there is no satisfactory research when it comes to the question how to place electrodes in a best way in order to acquire EMG signals during grip hand work. Our aim was to design a new measurement approach. Most common methods are based on using handles provided with force sensors [4]. This solution works best in laboratory research but when an experiment is carried out on real tools, it seems to be more complicated. This is due to the fact that a tool handle needs to be reconstructed. Publications [5–8] refer to the problem of modeling hand-arm system vibrations.

1.1. Physiology

Muscles are tissues well-specialized in changing chemical energy of organic substances, like glucose or fatty acids, to mechanical energy of the movements. This work focuses on skeletal striated muscles which are forming structures that are responsible for every form of mechanical activity of the body – the skeletal muscles.

Skeletal muscles consist of myocytes which, thanks to biochemical processes, are elements changing location towards each other or generating voltage between themselves. These processes are called the contraction. There are two types of contractions. The first type is called the isotonic contraction which maintains stable voltage during shortening the length of the muscle. The second type of contraction is called the isometric one because it is changing the voltage of the muscle without changing its length.

Skeletal muscles are never making contractions totally isometric or isotonic. Initially, while the voltage in myocytes does not balance the load, a muscle performs an isometric contraction. After exceeding this point, muscle must shorten to overcome the load. Such a biexpotential contraction is called auxotonic contraction and is the most common type of muscle activity [9, 10].

1.2. Electromyography (EMG)

To discuss the electromyography it is necessary to talk over the motor unit which is a group of myocytes together with a neuron that innervates them. Muscular fibers which create the motor unit are not collected in one branch, yet they are located on a big area between branches of other units. It has a decisive significance for the regulation of the contraction strength through increasing the frequency of discharge in single motor unit and through engagement of other motor units.

Electromyography is a technique connected with receiving, recording, and examining of myoelectric signals. These signals are coming into being thanks to physiological changes which are taking place in muscular fibers. Such signals can be registered through two types of electrodes:

• Needle electrodes —inserted straight into the muscle to show the signal of a single motor unit.

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• Surface electrode —put against the surface of the skin over an examined muscle to show a total signal of many motor units.

During relaxation, a muscle shows no electric relevant activity so that the electric line is straight. During the contraction, potential of motor units are deviating the EMG line. This line is a product of frequency and amplitude produced by registered potentials [9–11].

Electromyography is widely applied in medical science. Recommendations for the use of EMG include differentiation between muscle diseases and nervous system disorders, showing an extend of disease process, and monitoring treatment effects. EMG is also used in rehabilitation, sport medicine, and ergonomics [11, 12].

2. Research

On the basis of muscles characteristic we have assumed that EMG signals can be used to monitor grip force on the tool. We needed to prove that this is possible in every other circumstances.

2.1. Electrode placement

The muscles of a forearm are responsible for movements of the elbow and hand as well as for the supination of the forearm. They are divided in three groups: anterior (rear), posterior (dorsal), and lateral. This division is conditioned by the location of muscles towards to both bones of the forearm (ulna and radius) and towards the presence of interosseous membrane and intermuscular septum [13]. This work is about anterior division of forearm muscles which play the most important part in flexing many joints, also the joints of the hand. Also one muscle of the lateral division was examined which is taking part in bending only the elbow.

Muscles of an anterior division are grouped in two layers: superficial and profundus.

The superficial layer consists of [13]:

• Pronator teres muscle that supinates and flexes the forearm in the elbow.

• Flexor carpi radialis muscle that flexes the hand and fingers, also the elbow, but not so strong as the hand and fingers.

• Flexor carpi ulnaris muscle that flexes and adducts the hand.

• Palmaris longus muscle that flexes the hand.

The profundus layer consists of [13]:

• Flexor digitorum profundus that flexes and adducts the hand.

• Flexor pollicis longus muscle that flexes and abducts the hand.

• Pronator quadratus muscle that supinates the forearm.

In view of the authors' knowledge about the way of operation of an EMG and the way of collection of the signal through superficial electrodes, it has been decided to examine two muscles that are flexing the hand strongly and at the same time are situated most superficially. The strongest flexor of the hand is flexor digitorum superficialis. But it has not been taken under consideration because it is lying deeper than two others strong flexors of the hand: flexor carpi ulnaris muscle and flexor carpi radialis muscle. Other important factor that convinced the authors to choose these two muscles was the easiness of determination of location of the muscle belly with the help of some characteristic topographic point on the forearm.

The third muscle that has been chosen to this experiment was brachioradialis muscle which is a strong flexor of an elbow but it does not influence the movements of a hand. What is more, it lies superficially. This muscle was used to carry out a form of the blind test.

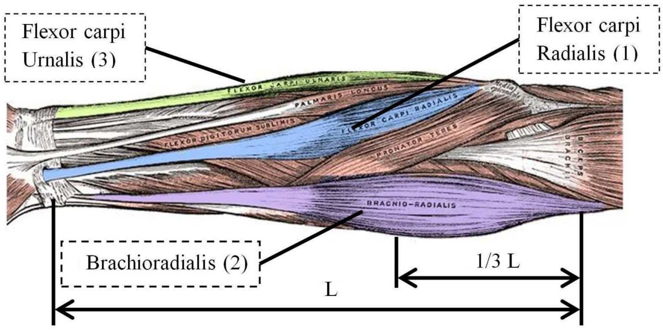

Fig. 1. Place of sticking the electrodes (after [14]).

The place of sticking the electrodes (presented in Fig. 1):

• Flexor carpi ulnaris muscle: a third of a way between medial epicondyle of the humerus and ulnar styloid process.

• Flexor carpi radialis muscle: a third of a way between medial epicondyle of the humerus and radial styloid process.

• Brachioradialis muscle: a third between lateral epicondyle of the humerus and radial styloid process.

The examination was carried out in two different positions of the patient's upper limb. The first one was the anatomical position which is a kind of the pattern according to which the human anatomy is described. Anatomical position for an upper limb is to place the palm straight ahead. In this location, ulna and radius are not crossing, so it is easy to locate the points to put the electrodes. The second position is a position of upper limb with palm rotating medialis. This is a natural and comfortable position for a human. The aim of these two positions is to show if during the rotation of a forearm there are some relevant dislocations between muscles and therefore it is necessary to examine a different uncomfortable anatomical position.

Another thing is the question whether the whole body position is having an influence on a hand grip force. Examination was taken in sitting and standing position.

2.2. Measuring system

Taking under consideration that a level of EMG signals was a few milivolts, we had to use a signal amplifier. The measurement set was designed to measure signals from three muscles at the same time. Signals were measured using differential amplifier schematic diagram of which is presented in Fig. 2.

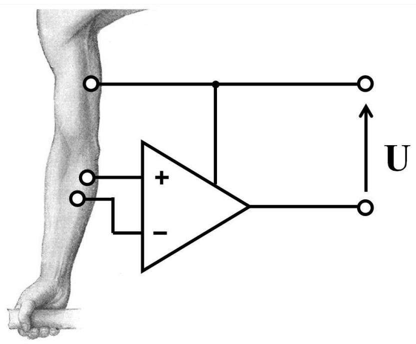

Fig. 2. Schematic diagram of electrode connections for Brachioradialis (after [14]).

This solution enabled us to eliminate artefacts from the final results. In addition, the measurements have been carried out on laptops with battery power only to isolate whole system from mains.

3. Research

The science of human anatomy has explored well the role of particular muscles in hand grip on the tool. Although we know techniques of EMG measurement, we are not aware of any research results when it comes to analysis what role each muscle plays in a particular task. In our research we have made an attempt to use sEMG to determine the strongest signal for one particular activity type — hand grip on the tool.

According to the theory, this should correspond to location of flexor carpi ulnaris or flexor carpi radialis.

The pilot study (range of forces 30–70 N) has shown that there were similar differences when it comes to EMG signals from particular muscles. This is why we have used the same clamping force (56 N) in the main study.

3.1. Measurement sessions

We have carried out significant number of measurements with two persons (a female and a male) in the following configurations:

- various postures: sitting (I), standing (II);
- various positions of limbs: anatomical (A), on outer side (B);
- various locations of electrodes: flexor carpi radialis (1), brachioradialis (2), flexor carpi ulnaris (3).

According to the above, 'IA2' stands for measurement in standing position (I), anatomical position of the limb (A), and with electrode placed over brachioradialis (2).

We have carried out a couple of measurement sessions for each person in all configurations mentioned above. One clamping force has been used for all sessions. It enabled us to compare how particular muscle parts respond to the impulse band of the same value.

In a single measurement round, the grip force was maintained for 6 seconds. After that, a repose lasted for 10 seconds. For each of the measurement configuration (e.g. IA1, IA2, IA3, IB1) several dozen of repetition have been done. A total of 540 measurements have been taken from the female subject and 498 from the male. For the purpose of analysis, we have taken a 5-second signal — the first and the last 0.5 second has been skipped.

Final signals have been digitally filtered with band-pass filters to eliminate distortions. EMG signals have been filtered with band-pass Butterworth filter characterized by the cut-off frequency of 100–500 Hz. For the signal from the grip force sensor, the band-pass Butterworth filter with the cut-off frequency of 10 Hz has been used.

4. Results

The coefficient of variation for the clamping force did not exceed 0.76% and had no impact on final results. This proves very good stabilization of the grip force.

All tests shown below were performed with statistical significance 0.05.

At first, we tested the effect of body and limb position on EMG results. In Table I we show the results of statistical analysis. We need to reject the hypothesis about compliance schedule of EMG signals with normal distribution (ND) (for male and female separately and without grouping). This means that we can not use parametric tests (PT) and should only use nonparametric (NT) ones. Despite this fact, we have decided to show results of homogeneity of variances (HoV) and ANOVA. However, these should only by treated as an additional reference.

TABLE I

Influence of body position (statistical analyzes): X – reject H_0; O – H_0 not reject; I – body sitting position; II – body standing position; A — anatomical limb position; B – on outer side limb position. BD — body, LI — limb.

	ND				PT				NT	
					HoV		ANOVA			
Position	BD		LI		BD	LI	BD	LI	BD	LI
	I	II	A	B						
All	X	X	X	X	X	O	X	O	O	O
Female	X	X	X	X	X	O	X	X	O	O
Male	X	X	X	X	X	O	X	O	O	O

The U Mann-Whitney test shows that we have no grounds to reject hypothesis that there are no mean differences between groups for body or limb position in any combination.

Bearing in mind that parametric tests are stronger than nonparametric ones, ANOVA test (with Brown–Forsythe tests for homogeneity of variances) was performed. Only in case of the limb position we have received the same results for parametric and nonparametric tests.

Figure 3 presents distribution of EMG signal that comes from particular measurement case without grouping.

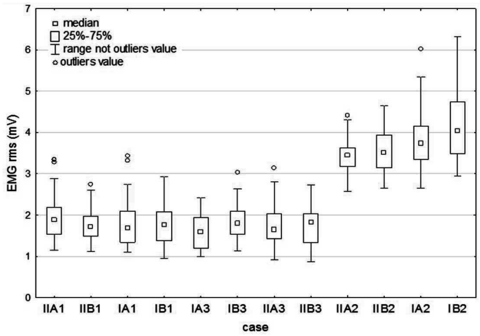

Fig. 3. EMG distribution.

We have noticed that EMG signal from brachioradialis was almost twice bigger than from the other muscles. Average coefficient of variation for brachioradialis for both sexes was 16.5%, while for flexor carpi radialis (1) is was 19.4% and for flexor carpi ulnaris (3) – 25%.

It proves that the results are more stable.

To show statistical significance of differences between particular cases (muscles, position and sexes), a nonparametric test was made. The results are presented in Table II.

TABLE II

Result of nonparametric tests: X — reject H_0; O — H_0 not reject.

	Kruskal-Wallis	U Mann-Whitney		
Electrode position	1, 2, 3	1, 3	1, 2	2, 3
Without grouping	X	O	X	X
Female	X	X	X	X
Male	X	X	X	X

The tests have confirmed graphical presumption. In the case of U Mann-Whitney test without grouping it has been confirmed that we have no reason to reject the null hypothesis that there are no mean differences between groups 1 and 3 (flexor carpi radialis and flexor carpi ulnaris). In the same test made with male and female separately we should reject the null hypothesis.

5. Conclusions

In this study we have defined the best location to measure sEMG signals during hand grip work. This is especially important because the input signal determines quality of further operations and inference. In this study we have used three measurement positions. The most sensitive location was over muscles brachioradialis (strong elbow flexor which does not impact the grip). Signals from flexor carpi ulnaris and flexor carpi radialis (both directly connected directly with the grip function) were significantly weaker.

Our analysis has shown that in deeper layer, under the brachioradialis muscle, there lies flexor digitorum superficialis, which is the strongest flexor of the hand (Fig. 4). The authors have came to the conclusion that the activity of this muscle has generated a strong EMG signal despite of the fact that this muscle lies deeper than brachioradialis muscle.

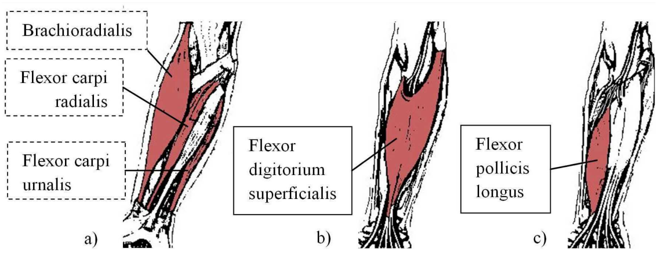

Fig. 4. Muscle in anterior view: (a) superficial, (b) middle, (c) deep.

Another conclusion is that we can ignore the impact of different body and upper limb positions as it has been noticed that in nonparametric tests there were no significant differences.

Acknowledgement

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