PROBLEMS IN ESTIMATION OF HAND GRIP FORCE BASED ON EMG SIGNAL

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Abstract

There has recently been a significant increase in the number of publications on and applications of bioelectric signals for diagnostic purposes. While the use of ECG (electrocardiography) is not surprising, the use of signals from registration of brain activity (EEG) and muscles activity (EMG) still finds new applications in various fields.

The authors focus on the use of EMG signals for estimating hand grip force. Currently, EMG signals are broadly used in limb rehabilitation after severe injuries, surgeries, long immobilizations. Such parameters as maximal voluntary contraction (MVC) used for that purpose do not enable comparison of the forces generated by the muscles, for example, of two different people. It is connected, *inter alia*, with individual features of the studied person, as well as with a significant scatter of the measured EMG values for the same muscle, e.g. on different days of EMG measurements.

The paper presents results of preliminary research whose final effect is to develop a procedure allowing force estimation in force units and estimation of the accuracy of the results. A series of tests was performed on two people. The tests showed the most important elements influencing disturbance of homogeneity of the obtained measurements with the same stimulation of the muscle. The authors focus only on determining hand grip force.

Key words: EMG analysis, EMG diagnostics, grip force, human hand.

PROBLEMY W ESTYMACJI SIŁY ZACISKU RĘKI BAZUJĄC NA SYGNALE EMG

Streszczenie

W ostatnich czasach można zauważyć znaczny wzrost ilości publikacji jak i zastosowań sygnałów bioelektrycznych w celach diagnostycznych. O ile nikogo nie dziwi stosowanie sygnału EKG (elektrokardiografia), to wykorzystanie sygnałów pochodzących z rejestracji aktywności mózgu (EEG) czy mięśni (EMG) nie stanowi nowum.

Tematem zainteresowań autorów jest wykorzystanie sygnałów EMG do szacowania siły zacisku ręki. Obecnie, można się spotkać z bardzo szerokim zastosowaniem sygnałów EMG przy rehabilitacji kończyn po silnych urazach, operacjach, długich unieruchomieniach. Wykorzystywane w tym celu parametry jak maximal voluntary contraction (MVC) nie umożliwiają porównywania sił generowanych przez mięśnie dla np. dwóch różnych osób. Jest to związane m.in. z czynnikami osobniczymi badanych, jak i z ze znacznym rozrzutem mierzonych wartości EMG dla tego samego mięśnia np. w różnych dniach wykonywania pomiarów EMG.

W pracy zaprezentowano wyniki wstępnych badań, których końcowym efektem jest opracowanie procedury, która umożliwi estymację siły w jednostkach siły, wraz z oszacowaniem dokładności uzyskanego wyniku. Dla dwóch osób wykonano serię badań, w wyniku których zaobserwowano najważniejsze z elementów wpływających na zaburzenia jednorodności uzyskiwanych pomiarów przy takim samym pobudzaniu mięśnia. Skoncentrowano się wyłącznie na wyznaczaniu siły zacisku ręki.

1. INTRODUCTION

Hand grip force on the handle of a tool and pressure force on the tool are some of the key elements affecting the actual impact when assessing vibration affecting man during work with hand tools.

Currently used measurement methods are based on the use of various types of adapters placed between the hand and the handle of the tool. Very often they significantly affect the work of the tool and vibration transmission in the tool - the operator system.

Another solution is to use a special handle with a built-in system of force sensors, which enables measurement of grip force [1, 2]. It is a very good solution limited, however, exclusively to applications in a laboratory environment. Examples of such an application is presented in Fig. 1.

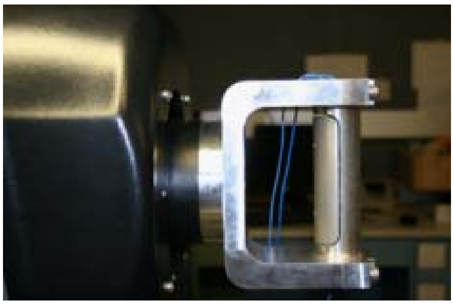

Fig. 1. A device used to measure the biodynamic response of hand–arm system [1]

In recent times, there were other solutions that allowed measuring not only the grip force but also determining the force from individual fingers. Force sensors placed in a glove put on the hand of the studied person were used for that purpose (Fig. 2) [3].

Fig. 2. Finger force measurement system (volar side) [3]

All of these solutions have one important defect consisting in introducing an element affecting the transmission of the vibration between the elements of the tool – hand system. Therefore, there is a need for a system which would allow a non-invasive measurement of grip force *in situ.*

In this publication, the authors tried to introduce the idea of such a solution based on the use of bioelectric signals from the muscles responsible for hand grip. Efforts were also made to indicate the problems that need to be addressed in order to obtain reliable results.

2. BASE THEORY

The numerical values of electric potentials and their graphic representation recorded by the use of electromyographic tests are a starting point of an objective examination of the functional state of muscle tension. Muscle contraction occurs when the muscle is electrically provoked, and current is produced in the muscle during its contraction. Electromyography (EMG) deals with recording electrical activity of muscles. Electrical activity is connected with permeability of sodium and potassium ions through the membrane of the cell. Polarization of electric charge inside the cell in relation to the cell membrane occurs due to the uneven distribution of sodium and potassium ions in a muscle cell .

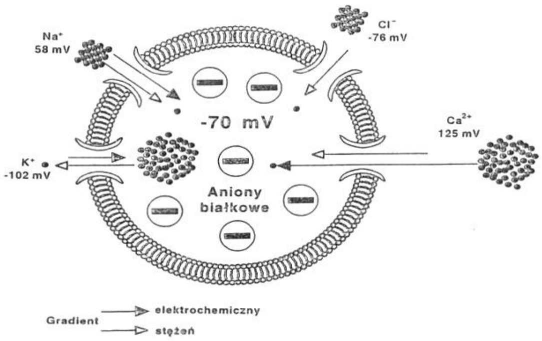

Fig. 3. Diagram of electric impulse production in a muscle cell [4]

Polarization potential, which in resting position is about 80 mV, changes, depending on the functional state of the muscle [5]. A small contraction is enough to register the so called potential of a motor unit. By analyzing the collected signals, their shape, course, amplitude, frequency and duration of discharges, we can assess the performance of the muscle. Efficient muscle in resting position does not cause any of the electric activity mentioned above.

3. EXPERIMENTAL TESTS

1325 measurements using surface EMG sensors were made in this study. Registration of the signal collected from the finger flexor muscles (II-IV) was made at hand grip force of 25, 50 and 75N.

3.1. Measurement system

The devices for registration and analysis of EMG signals available on the market have closed architecture. Used for medical purposes, they have typical and proven functionalities but they usually offer only a few algorithms and no options for export of recorded EMG signals and their analysis with external software.

That is why it was necessary to develop our own system that would enable implementation of calculation algorithms but also have the architecture open to the extent that it would in the future enable implementation of new functionalities (such as, for example, cooperation with atypical sensors).

The schematic diagram of the measurement system used is presented in Fig. 4. Its main elements are: electrodes, differential amplifier of bioelectric signals, DAQ card with AC converter (resolution 16 bit), software for registration and analysis.

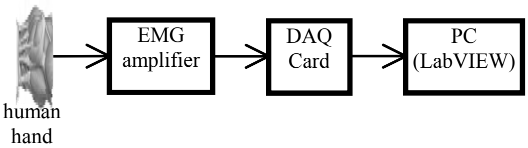

Fig 4. Schematic diagram of the measurement system

The differential amplifier is responsible for amplification of bioelectric signals collected from selected muscles by the use of two electrodes. Then the muscle potentials of <2mV are amplified to ca 5V and processed with a measurement DAQ card. Using the signal analyzing and registration software is the last element.

The device amplifies small signals, which enables using it for registration of EMG signal.

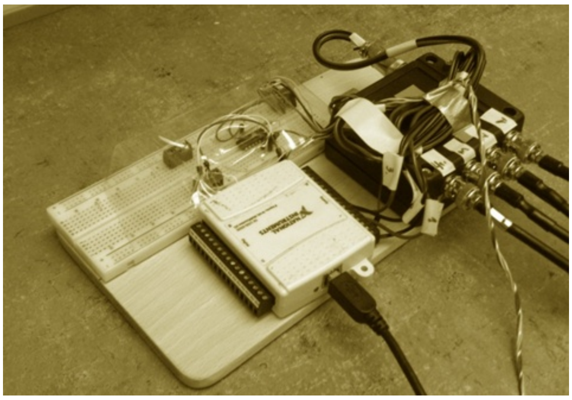

Fig. 5. EMG signals registration system

3.2. Measurements

Since EMG test is a complex process and since it is important to prepare well for the test and to select a suitable place, the initial tests were performed on the medial forearm, examining finger flexors. After consultations with medical doctors, using palpation examination and trial EMG signal readings, we selected points where the registered signal was the best (minimizing sounds from neighboring muscles and of the highest level). [6] The fixing points for the electrodes were marked in the distal third of the forearm between the *palmaris longus* and *flexor carpi ulnaris* muscles. The other electrode was placed 4 cm closer to the distal part.

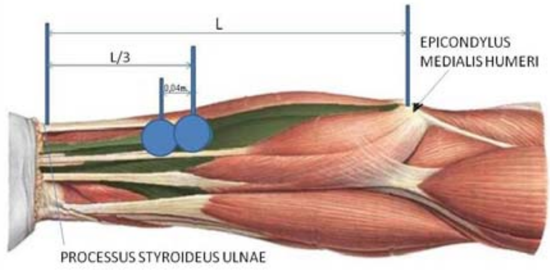

Fig. 6. Location of electrodes on a forearm

The tests involved two women, aged 25 and 26 of similar height (1,67 and 1,65m) and body mass of 58 and 59 kg. The tests were made over a period of three months, in one room, in similar conditions. Constant temperature (air conditioning), no control of humidity and pressure. Measurements were taken twice a week, with a few measurement series at each session. One series is 10 hand grips with a desired force recorded by the dedicated handle. Handle was designed by using strain gauge sensor with two special formed covers on each side of sensor. Handle was earlier calibrated. The registration software made sure that the grip force during the measurements did not exceed +/-5% of the given value. When the deviation was bigger, the measurement was interrupted, and then resumed after a suitable resting period. (acceptable deviation of 5%). Each grip lasting 5 seconds was followed by a minimum of 5 seconds of rest.

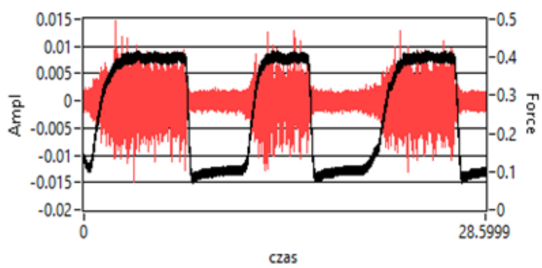

Fig.7. EMG signal (red) and force (black) in time

EMG signal was registered for the hand grip with the force of 25, 50, and 75 N. The tests were performed in a sitting position. The forearm of the person was placed on a table, which allowed relaxation of the muscles between grips. The hand in an anatomical position, palmar part upwards. Hook grip. National Instruments USB6212BNC and LabVIEW 2013 software were used to register the signals. LabView has already confirmed its reliability of the dedicated measurement systems [7]. The developed software enabled registration. Additionally, each measurement session had a number of metadata identifying the person, *inter alia*, personal details (age, weight, gender, etc.), place of the measurement, grip force applied.

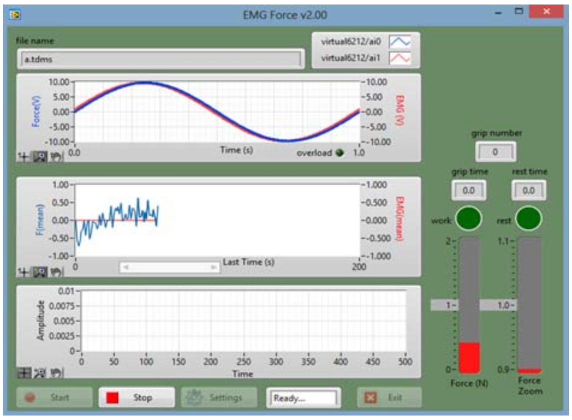

Fig. 8 Software developed in LabVIEW environment, recording time

The developed software was to enable export of measurement data to any format, to enable further analysis in any programming environment.

4. ANALYSIS

EMG signals are analyzed by the use of various calculation algorithms, for example, well known methods based on frequency analysis of EMG signal [8] [9] are used for detection or observation of muscle fatigue or a change in muscles position. The EMG signal analysis for detecting the degree of muscle contraction is a commonly used parameter for example. Maximal voluntary contraction (MVC) [9] is the parameter generally used in the analysis of EMG signals to detect muscle contraction.

Since electric potential of the muscle activity recorded is proportional to the muscle contraction, that is the force it generates, it was decided that the analyses would be based on the well-known parameter, that is the value of RMS (root mean square). Based on previously conducted studies [6], it is assumed that it will be a good parameter describing force.

Statistica version 10 was used to make all the presented statistical analyses.

The first analyses were made separately for both subjects.

11 series of measurements included nearly 1,300 five-second measurements of hand grip of the measurement handle, with at least five seconds rest between each of the measurements.

The first element was to test the hypotheses on the consistence of the distributions of the tested parameters with a normal distribution. Two types of tests were performed, Kolmogorov-Smirnov and Lilliefors. As a result, information was obtained about the lack of evidence to reject the zero hypothesis of a normal distribution in the tested groups. The results are shown in Table 1.

Table 1. The results of the analysis

Patient	Testend Hand	Nominal Force (N)	N	K-s	Lillief.
A	left	25	314	p > ,20	p < .15
A	left	37	76	p < .20	p < .01
A	left	50	273	p > ,20	p < .01
A	left	62	78	p > ,20	p < .05
A	left	75	218	p < .05	p < .01
A	right	25	50	p > ,20	p < .10
A	right	50	50	p > ,20	p > ,20
A	right	75	51	p > ,20	p > ,20
B	right	25	46	p > ,20	p > ,20
B	right	50	62	p > ,20	p > ,20
B	right	75	76	p < .15	p < .01

N- Numbers of measurements

The basic assumption of the research was that the rms value of the recorded EMG signal is proportional to the force of the hand grip on the handle.

Therefore, the next step was to examine the distribution of changes of rms (EMG) depending on the grip force for each person. Due to the fact that both were right-handed, the analysis focused on the dominant hand. The results of the distributions are presented in Fig 9.

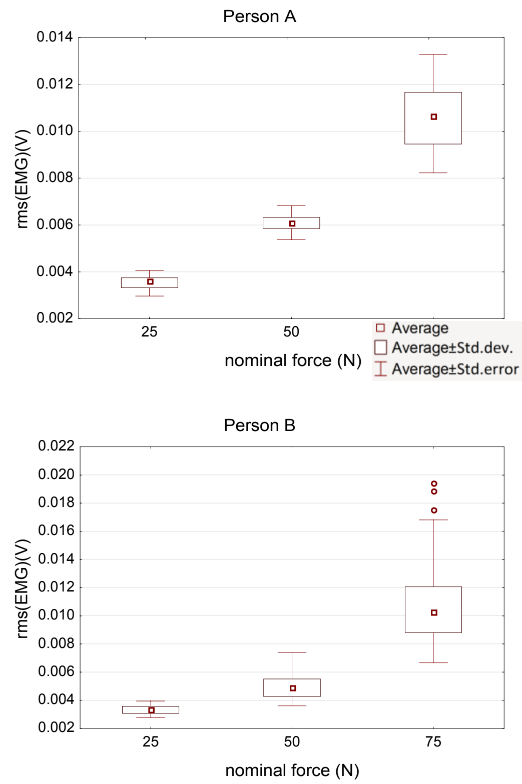

Fig. 9. EMG signals for different grip force (upper person A, lower person B)

Although the visual analysis of the drawings presented in Figure 9 suggests that there is a strong dependence of the rms signal (EMG) and the force, it was decided to use the one-way ANOVA. It allows determining whether there is a statistically significant difference between the levels of the rms signal (EMG) for different grip forces (25N, 50N, 75N) for each of the subjects separately. The analysis assumes meeting two conditions, the normal distribution of the tested groups and the homogeneity of variance of the tested persons. While in most cases there was no evidence to reject the hypothesis of distribution consistent with the normal distribution, a test of homogeneity of variance (Levene's test) showed statistical significance. Therefore, continuation of one-way analysis of variance is not justified.

However, RIR Tukey test (from the post-hoc package of analyses), providing information which differences between the groups are significant was made. That analysis showed that for all pairs, except one (patient B, the pair of forces 25N, and 50N) there are noticeable differences between the averages of the tested groups.

Nonparametric U Mann-s tests, for which H_0 is: two randomly selected groups come from the same population [10], were made.

Table 2. Results of nonparametric tests: X-reject H_0 ; O-H_0 not reject

force pair	25N-50N	50N-75N	25N-75N
Patent A U Mann-Whitney	X	X	X
Patent B U Mann-Whitney	X	X	X

In all studied cases it is justified to reject H_0 and say that there is a statistically significant difference between the studied groups.

The above results and diagrams for the groups without identification of the studied persons (Figure 9) turned out to be so optimistic that we decided to make the same statistical analyses as before.

So for the studied forces of 25N, 50N and 75N of a bigger group of results (results for person A and person B), the necessary steps were taken to make ANOVA tests.

The tests for normal distributions only in the case of 50N force did not justify rejection of H_0 on consistency of the distribution with the normal distribution.

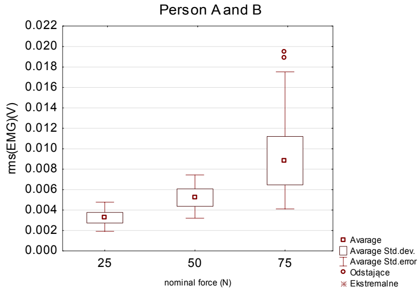

Fig 10. EMG signals for different grip force (both person A and B)

Nonparametric test had to be made. U Mann-Whitney's test was made. The results are presented in Table 3.

Table 3. Results of nonparametric tests: X-reject H_0 ; O-H_0 not reject

force pair	25N-50N	50N-75N	25N-75N
U Mann-Whitney	X	X	X

For all the tests the significance was less than 0.05. That is why H_0 was rejected and it was stated that there is a statistically significant difference between the results obtained with different grip forces.

5. SUMMARY

The research presented in this paper was to check if there is a difference between the results of EMG signal obtained during hand grip. The tests were made for three arbitrarily selected forces (25N, 50N and 75N) and for two persons. The statistical analyses focused on the results for the dominant hand (right in both cases).

The statistical analyses confirmed that there is a statistical difference between *rms* value of a five-second EMG signal between all the studied grip forces.

Furthermore, the difference was significant both for the group of the results obtained individually for each of the studied persons separately and for the group of the results common for both studied persons.

The above results confirm our assumption that it is possible to develop a procedure enabling determination of the force used based on EMG signal, expressing it in newtons (N).

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