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# Identification of muscle movements and activity by experimental methods for selected cases – stage#1

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*Purpose*: The aim of this study was to determine the position where the most activated and isolated individual muscles were. In the next steps, the selected limb positions will be used to determine the maximum values of isometric forces of the individual muscle heads based on the Hill model. *Methods*: In order to determine the sought muscle activation, an electromyograph was used. Isometric contraction measurements were carried out for seven series of tests. Isometric contraction was performed as 100% MVC. *Results*: For the long head of the biceps muscle, in the case of bending in the shoulder joint, angle of 75° was selected and for abduction in the shoulder joint – 90°. Internal rotation in the shoulder joint was omitted because of lower activation values. For the short head of the biceps muscle, the angle characterized by the greatest activity of the head was the angle of 115° in flexion at the elbow joint. The selected angle was 30° for shoulder extension and 110° for shoulder adduction. For the lateral head of the triceps brachial muscle, measurements showed that the angle at which the lateral head was most activated is 115°. *Conclusions*: The aim of this study was to determine the positions of the arm muscles that activate and isolate individual heads the most. The research presented and achieved results concern one specific person for whom a personalized numerical model was developed to represent the flexion-extension movement at the elbow joint. The performed tests can also be a preliminary assessment of the upper limb positions, for which wider conclusions could be drawn in the case of measurements on a larger number of participants.

*Key words*: *EMG, biceps brachii, triceps brachii, MVC*

## 1. Introduction

Surface electromyography (sEMG) measures the electrical signal on the skin's surface, generated by skeletal muscles. Despite historical observations, animal studies and the finding that muscles are a source of electricity, sEMG currently is mainly used in the study of human muscle systems [29].

The measurement of data parameters using sEMG technology in animals is quite a challenge. This is due to the lack of standardization in the measurement methodology, i.e., the arrangement of electrodes and the methods of processing these signals [53]. Over the years, the above measurement technology has undergone significant development, which, consequently, allowed for the development of some standardization in the case of tests in humans. The sEMG signal processed over time provides information on muscle activity, enables the estimation of strength values and can be an indicator of the level of muscle fatigue [28].

Due to its versatile application, it is used in many areas, especially in clinical trials, medical and sports rehabilitation, physiotherapy, ergonomics, biomechanics, etc. [18], [36]. One of the elements of the human body to which significant amount of research using surface electromyography has been devoted are the lower limbs [27]. This is due to the fact that they are traffic organs enabling mobility, which is considered a basic and everyday activity of non-disabled [22], [24], [51] and some disabled people [5], [31], [54]. Various forms of locomotion have been tested, including run-

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ning and walking [46]. The studies devoted to the muscle groups of the lower extremities also covered the influence of footwear on the activation of individual muscles [19], [45], the influence of the ground [26], [38] and the impact of leg prostheses on everyday life [48], [55]. The few presented examples of the use of sEMG as a research method for lower limbs are only the tip of the iceberg when it comes to studies and publications that have been made on the subject. For this reason, the research in this publication focuses on the upper limb.

In recent years, one of the disease cases requiring professional identification with the use of sEMG technology is the study of hemiparesis, which results from strokes and micro-strokes, and which results in the loss/limitation of the functionality of the upper limb. An example of the use of sEMG in upper limb clinical trials can be found, for example, in the study [40] where it was assessed how healthy people activate and coordinate muscles during typical upper limbs clinical tests. The results indicate the establishment of baselines for neurological trauma patients, noting that healthy individuals require a lower level of activation and co-contraction of muscles in tasks simulating daily activities. The study [6] compared the muscle activity of the upper limbs during elbow flexion in healthy people and in people after a stroke. Based on the measurements, it has been found that it is difficult to draw general conclusions about the consequences of a stroke on muscles with partial paresis. According to the authors, the doubts in the conclusions are caused by the difficulty in finding a posture or a static task that allows for the achievement of maximum isometric strength even in healthy subjects. This is precisely what this study is devoted to and described in the following sections of this article. The study [33] analyzed the effect of age on upper limb muscle activity during a fall in outstretched hands, which is a much more common event affecting the elderly. The authors indicated an irregularity among older women, characterized, among others, by greater stiffening of the shoulders, thus increasing the risk of injury. The aim of the study [32] was to compare the peak sEMG amplitude of muscles on the dominant and non-dominant side during bench press exercises. Regardless of the external load, the dominant side showed a much higher peak sEMG amplitude, which, in turn, could lead to muscle failure. Also in many sports disciplines, the upper limb plays a key role and is often subjected to significant loads, resulting in numerous injuries. A systematic review [10] focusing on the biomechanics of baseball throws summarized the study by stating that the sEMG activity of the elbow wrist flexor muscle was reduced in pitchers with elbow injury, but pointed out to the need for more research to determine whether strengthening the muscle reduces the risk of injury or recurrence of injury. A review [4] assessed the existing literature with regard to sEMG measurements of the forearm muscles in tennis. The literature suggests increased activity of one muscle among less experienced players, while there is no evidence of a relationship between the techniques of swinging and the development of an increasingly common injury, even among people who do not play sports – the tennis elbow. On the other hand, limitations in studies that evaluated assessing the relationship between muscle activity and tennis elbow were indicated due to heterogeneity in methodological projects and the lack of sufficient information on the sEMG methods used.

Another group are musicians who perform intense, repetitive tasks that can lead to many conditions. The study [15] investigated the influence of touch and articulation on the activity of the upper limb muscles among pianists. Based on the measurements, the authors identified the triceps muscle of the arm as the main, most active muscle during keystrokes. Additionally, the results presented suggest that warm-up procedures that combine touch and articulation may prevent musculoskeletal disorders associated with playing the instrument.

Muscle activation makes it possible to estimate the forces generated, which, in turn, play a significant role in biomechanics as well as in clinical applications, thus influencing physicians and rehabilitants in decisions concerning diagnosis and treatment [16]. The forces generated by a given muscle cannot be measured directly and non-invasively. Muscle strength depends, among others, on the number of activated motor units or their cross-sectional area [37]. In publication [50], the authors emphasize that to correctly estimate the strength based on sEMG, the following should be taken into account: the nature of the sEMG – strength relationship, differences in time characteristics between the sEMG signal and the strength signal, normalization of the sEMG signal and the influence of the dynamics of muscle contraction. Furthermore, there are factors that are not reflected in the sEMG signal, but affect muscle strength, such as muscle length, muscle contraction velocity and fatigue. In connection with the presented guidelines, a solution is suggested in which, for specific positions, sEMG enables a useful estimation of muscle strength – isometric contractions. The static work of the muscle makes it possible to ignore the influence of changes in the length of the muscle and the speed of its contraction. Isometric contraction is recommended to determine the Maximal Voluntary Contraction (MVC), which is also often used in the normalization of the sEMG signal, because it allows for comparison of muscle activity between muscles, tasks and people [11], [12]. An example of the use of MVC can be found in [49], where differences in muscle activation patterns were assessed when performing three tests of hand fitness. Based on the measurements, it was found that one of the three tests affected different muscles than the other two tests, and women showed more muscle activity than men. The authors conclude that occupational therapists should be aware of the influence of muscles on the results of fitness tests. The aim of the study [3] was to determine the tasks that cause MVC in the forearm muscles. Nine isometric tasks were performed involving all muscles capable of participating in a particular exercise. Based on the collected data, the authors claim that a targeted protocol can be designed to alleviate the fatigue effects of the forearm muscles. Maximal voluntary contraction was also used in [7], but the authors of the experiment performed measurements with variable MVC load to determine upper limb muscle fatigue. The obtained results indicate a more precise analysis of muscle fatigue at lower load levels, i.e., 30% MVC. When a muscle is subjected to constant isometric force, the EMG signals show characteristic changes that correspond to muscle fatigue. The quantities that indicate the level of muscle fatigue include an increase in the amplitude of the signal and a decrease in frequency during a long-term isometric contraction [14], [23]. Therefore, thanks to sEMG, there is a non-invasive method for examination of muscle fatigue, which, in turn, finds its use in ergonomics [25]. However, the subject of muscle fatigue deserves a separate and in-depth analysis.

One of the main research directions undertaken by the authors are experimental studies of the muscles of the upper limb, which ultimately serves to develop the method of numerical research. One of the most popular and versatile methods is the research using the finite element method. It is a tool that has recently provided a wealth of knowledge, due to the development of computer mechanics methods impossible to obtain through *in vivo* tests, e.g., the assessment of the level of stress/strain in hard and soft tissues and the estimation of loads on elements of the human musculoskeletal system during movements [43]. Skeletal muscles are characterized by the ability to contract to half their length, which is related, among others, to complex mechanical properties. Currently, the most frequently used mathematical description of the mechanics of muscle contraction is the Hill model. The proposed model consists of a contractile element and a parallel elastic element, where it can additionally be supplemented with a series element representing the work of the tendons. In numerical analyzes, the taking muscle activity into account is used mainly in simulations examining human reactions during traffic accidents [52].

The aim of this publication was to determine which tasks are most likely to cause MVC in the two muscles of the arm, taking their structure and division into individual components into account. Based on the collected data, a targeted protocol can be designed for the biceps brachii and the triceps brachii. For the work related to numerical analyses, the performed measurements are necessary to determine the parameters for the Hill model, i.e., the value of the maximum isometric force of individual muscle heads. Isometric forces are to be calculated based on the values of torque obtained through future experimental research.

# 2. Materials and methods

## 2.1. Object of interest

The analyzed muscle group was the arm muscles, which are divided into two groups: anterior – flexor muscles and posterior – extensor muscles. The anterior group includes: coro-brachial, brachial and biceps muscles. The second group consists of only one muscle – the triceps of the arm. Each of these muscles has a different function, but the synergy of their action allows for a full range of movements of the limb.

The arm biceps muscle was the first subject of this study. It is a muscle with two heads that runs from the scapula to the radius bone. It consists of a long head and a short head. The biceps muscle is a two-joint muscle – it stretches over the shoulder and elbow joints. Its effect on movements in the shoulder joint is by about 1/3 weaker than in the elbow joint.

The second muscle to be examined is the back muscle – the triceps muscle of the arm. It covers the entire back surface of the arm. It begins with three heads, one of which – the medial head is the deep part of the muscle, located on the humerus. The other two heads – long and lateral – are surface heads. The common tendon of all three heads ends at the ulna. The effect of the triceps muscle on the shoulder joint is about half as great as that of the elbow joint. The entire muscle works to extend the elbow joint [8].

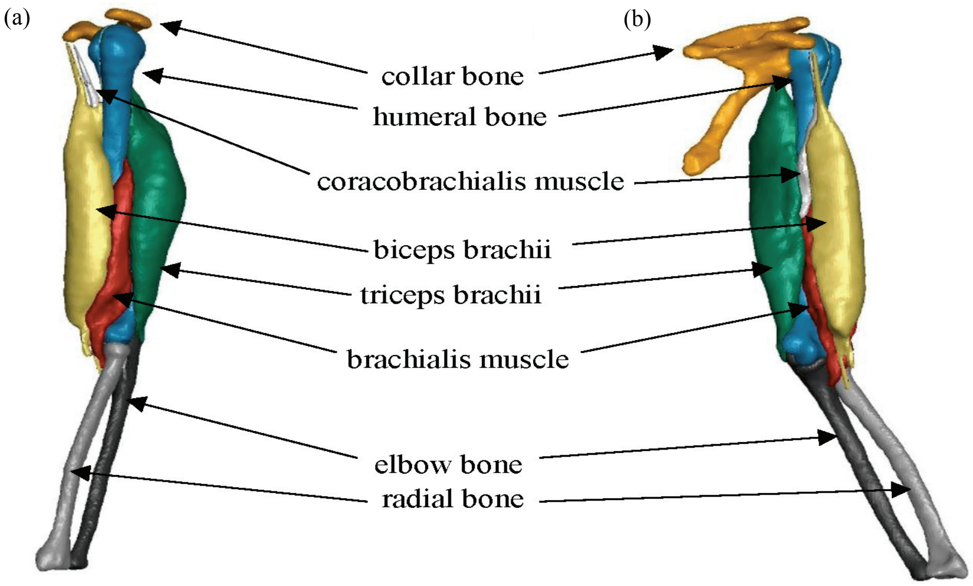


Fig. 1. Geometric model of the skeleton of the left upper limb and the arm muscles:
a) view from the outside, b) view from the inside

In Figure 1, the geometry of the arm muscles and the skeleton obtained on the basis of magnetic resonance imaging are shown. The non-invasive study was conducted on a 35-year-old man, 182 cm tall and weighing 72 kg. The next stages of the research, which are presented in the subsequent stages of this work, were also carried out on the same individual. The volume of the triceps brachial muscle in the subject was 567.409 mm$^3$, while the volume of the biceps brachii was 277.869 mm$^3$.

## 2.2. Experimental protocol

On the basis of consultations with a physiotherapist, movements of the upper limb were identified. Each of the examined heads was analyzed separately, focusing on determining the movements that maximally activate and isolate individual muscle heads. This way, the positions of the limbs were selected. The positions of the four surface heads, which were tested depending on the angle of flexion at the elbow and brachial joints, are shown below. At this stage of the study, the medial head of the triceps brachial muscle was omitted due to its location, which made non-invasive measurement impossible.

Identified movements for the long head of the biceps brachii:

- Bending in the shoulder joint – range of motion in the joint (ROM) = [–30°; 90°] – measurement every 15° (Fig. 2),

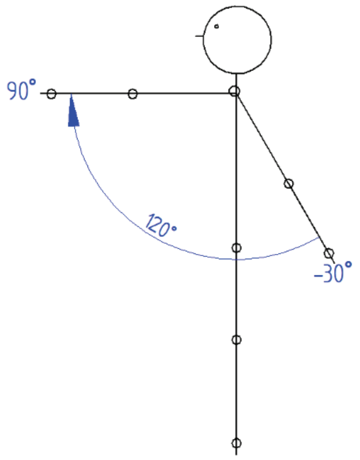


Fig. 2. Bending in the shoulder joint (sagittal plane)

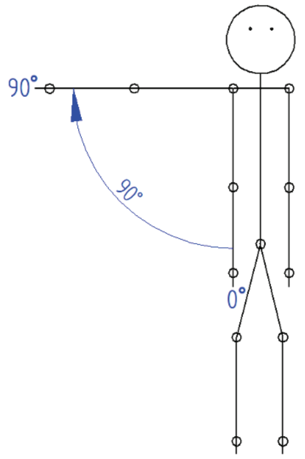


Fig. 3. Abduction in the shoulder joint (frontal plane)

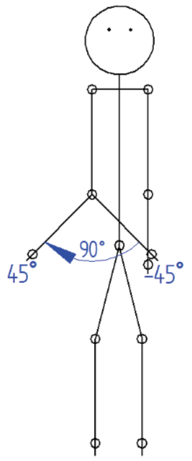


Fig. 4. Internal rotation in the shoulder joint (frontal plane)

- Shoulder Abduction – ROM = [0°; 90°] – measurement every 15° (Fig. 3),
- Internal rotation in the shoulder joint – ROM = [–45°; 45°] – measurement every 15° (Fig. 4).

The short head of the biceps brachii is most active during:

- Elbow bends – ROM = [0°; 120°] – measurement every 15°, except for the last angle where the difference was 10°, because the test subject did not reach the maximum elbow flexion of 120° (Fig. 5).

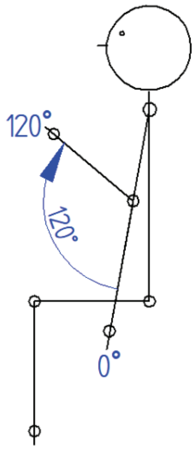


Fig. 5. Bending in the elbow joint in a sitting position (sagittal plane)

For the long head of the triceps muscle, the designated movements for research were:

- Straightening in the shoulder joint – ROM = [–30°; 90°] – measurement every 15° (Fig. 6),

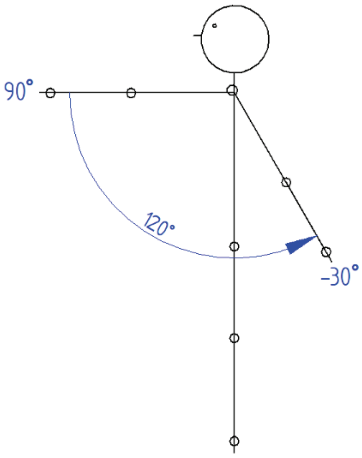


Fig. 6. Straightening in the shoulder joint (sagittal plane)

- Adduction in the shoulder joint – ROM = [80°; 110°] – Due to the small range of motion during this task, measurements were taken every 5° (Fig. 7).

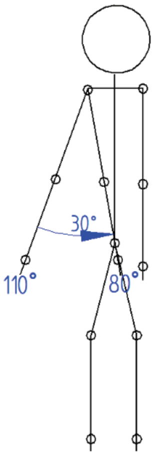


Fig. 7. Adduction in the brachial joint (frontal plane)

On the contrary, the lateral head of the triceps brachial muscle is responsible for:

- Straightening in the elbow joint – ROM = [0°; 120°] – measurement every 15° except for the last angle where the difference was 10°, because the test subject did not reach the maximum elbow flexion of 120° (Fig. 8).

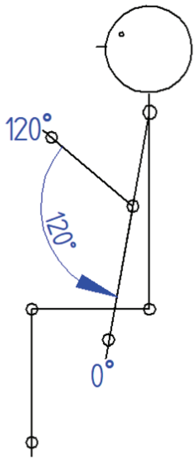


Fig. 8. Straightening in the elbow joint (sagittal plane)

Measurements of the isometric contraction were carried out for the above-mentioned seven series of tests, where each series consisted of seven or nine measurements – depending on the number of analyzed bending angles for a given task. The order of the angles selected for the tests was random. Each measurement series was repeated three times. Measurement of the isometric contraction lasted 10 seconds. After each 10-second effort, the muscle recovery time was 3 minutes, thus avoiding the appearance of muscle fatigue. Isometric contraction was performed as 100% MVC.

## 2.3. Data recording

Experimental studies were carried out on a 35-year--old male without any musculoskeletal problems in the upper limb. In order to determine the sought muscle activation, an electromyograph, which enables non-invasive measurement of surface muscle stimulation was used. Measurements were carried out on a sEMG by Noraxon, USA, with a built-in bandpass filter for the frequency of 10–500 Hz. Signal processing was performed with MR 3.14 software. Bearing in mind the publications of other authors, including [13], [20], [39], the EMG signal was recorded with the highest available sampling frequency – 2000 Hz. Before applying the measuring electrodes, the skin was cleaned with alcohol to remove impurities and dead epidermis. According to [21], the measuring electrodes were glued in the area of the upper part of the heads, thus making it possible to distinguish them. In Figure 9, the measurement points are shown.

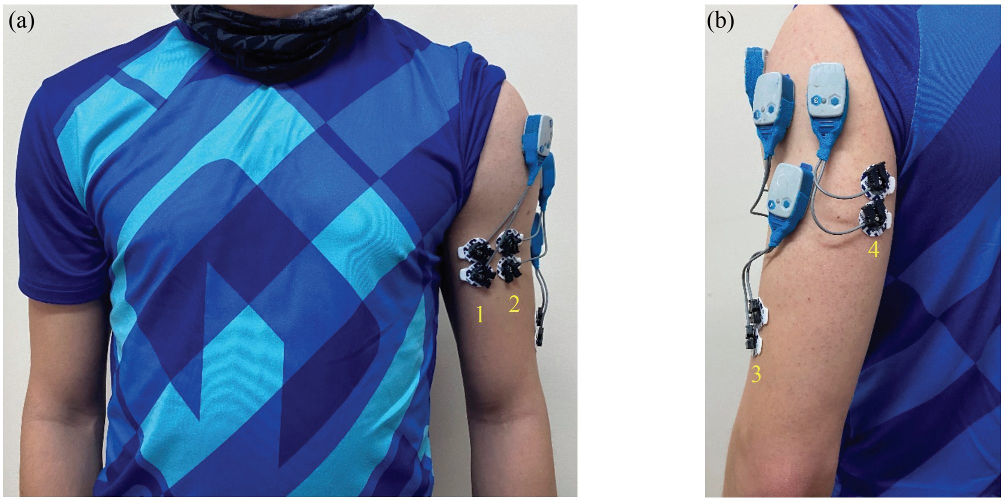


Fig. 9. Measurement points: (a) biceps: 1 – short head, 2 – long head; (b) triceps: 3 – lateral head, 4 – long head

In this stage of the study, the Biodex System 4 Pro isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA) was used to immobilize the body and position the limb in a specific position in the shoulder and elbow joints as well as in a specific flexion angle.

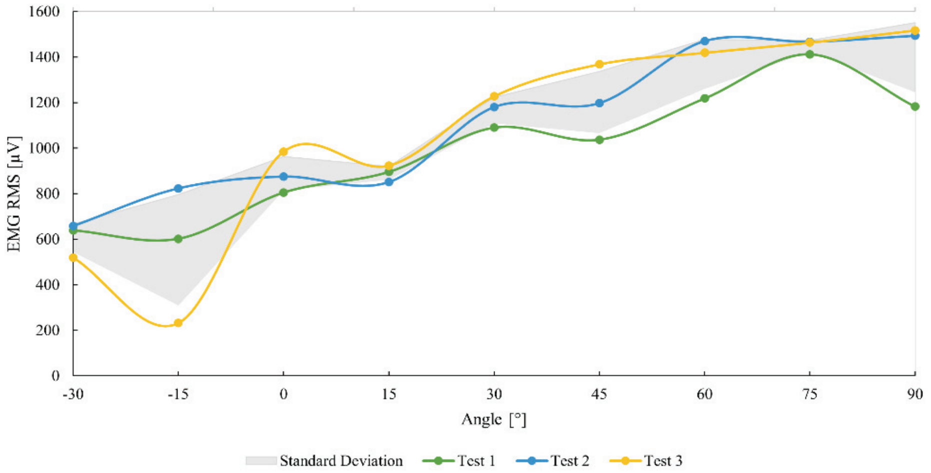
## 3. Results

The graphs show the waveforms of the three activity measurements, depending on the flexion angle for each task that activates the given muscle heads. The area of the mean value from three measurements +/– population standard deviation was marked in gray. The tables summarize the mean of the three measurements, thus determining the flexion angles under which the given head is characterized by the greatest muscular activity. The EMG signal was processed by a bandpass filter with a frequency of 10–500 Hz built into the device. To be able to compare and juxtapose the results obtained, the absolute value for the entire signal was determined and the root mean square (RMS) with a moving window of 100 ms was used from 200 samples. These parameters were selected on the basis of data from the literature [12], [32], [47]. Muscle activity is expressed in μV.

### 3.1. Results for the biceps brachii muscle

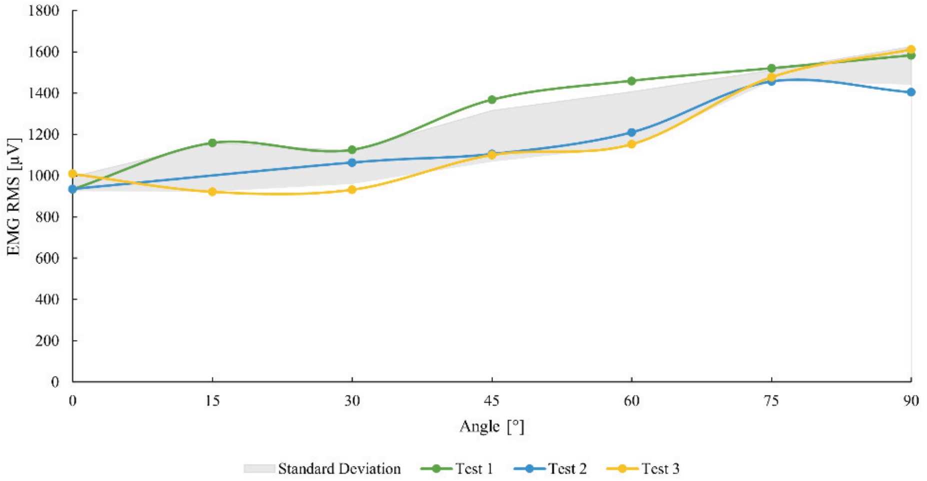
For the long head of the biceps muscle, during flexion (Fig. 10) and abduction (Fig. 11) in the shoulder joint, there is a noticeable increase in activity with an increase in angle. In these tasks, the angles selected for further research are characterized by a similar level of muscle activity, and are at the level of around 1500 μV. For internal rotation in the shoulder joint (Fig. 12), the activity of the long head at all angles is about a thousand units lower.

When flexing the elbow (Fig. 13), the position of the limb in which the short head of the biceps brachii is activated, an upward trend in activity can be noticed. Here, too, the maximum activity, which being the average of the three measurements, is around 1500 μV.



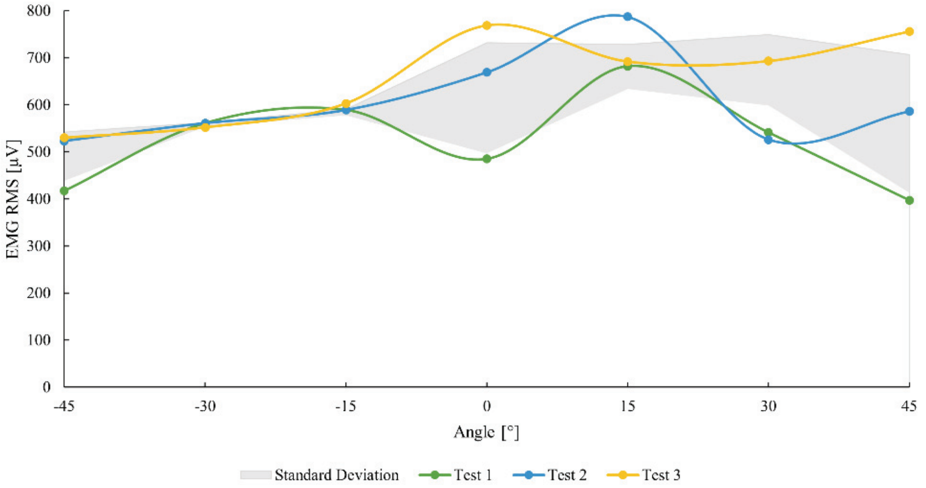
| Angle [°] | EMG RMS [µV] |
|---|---|
| –30 | 605.261 |
| –15 | 552.375 |
| 0 | 888.310 |
| 15 | 890.073 |
| 30 | 1166.221 |
| 45 | 1201.18 |
| 60 | 1369.294 |
| 75 | **1447.891** |
| 90 | 1397.992 |

Fig. 10. Muscle activity as a function of the angle for bending in the shoulder joint – the task of activating the long head of the biceps muscle



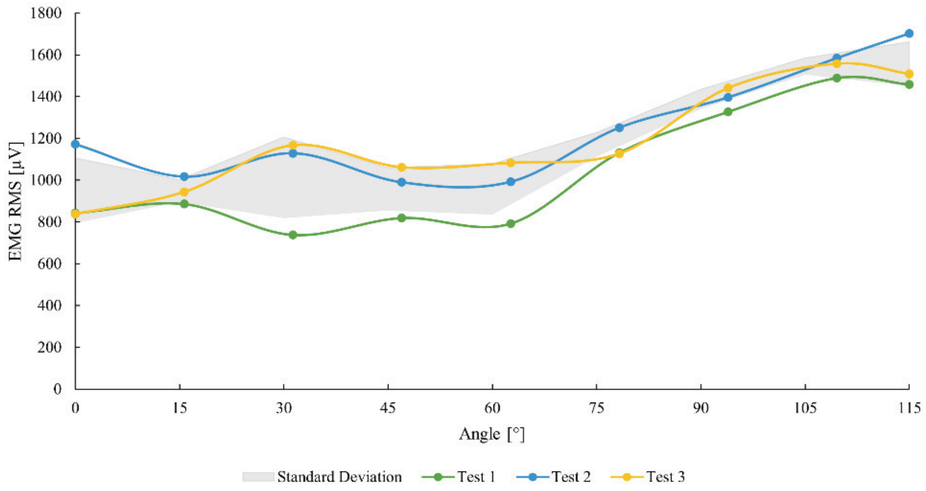
| Angle [°] | EMG RMS [µV] |
|---|---|
| 0 | 959.739 |
| 15 | 1040.569 |
| 30 | 1040.764 |
| 45 | 1191.486 |
| 60 | 1274.215 |
| 75 | 1484.88 |
| 90 | **1533.085** |

Fig. 11. Muscle activity as a function of the angle for shoulder abduction – the task of activating the long head of the biceps muscle



| Angle [°] | EMG RMS [µV] |
|---|---|
| –45 | 490 |
| –30 | 558 |
| –15 | 584.333 |
| 0 | 614.333 |
| 15 | **681** |
| 30 | 673.667 |
| 45 | 559.667 |

Fig. 12. Muscle activity as a function of angle for internal rotation in the shoulder joint – the task of activating the long head of the biceps muscle



| Angle [°] | EMG RMS [μV] |
|---|---|
| 0 | 950.333 |
| 15 | 948.667 |
| 30 | 1011.333 |
| 45 | 957 |
| 60 | 955.667 |
| 75 | 1169.667 |
| 90 | 1388 |
| 105 | 1543.667 |
| 115 | **1556.333** |

Fig. 13. Muscle activity as a function of the angle for flexion in the elbow joint – the task of activating the short head of the biceps muscle of the shoulder

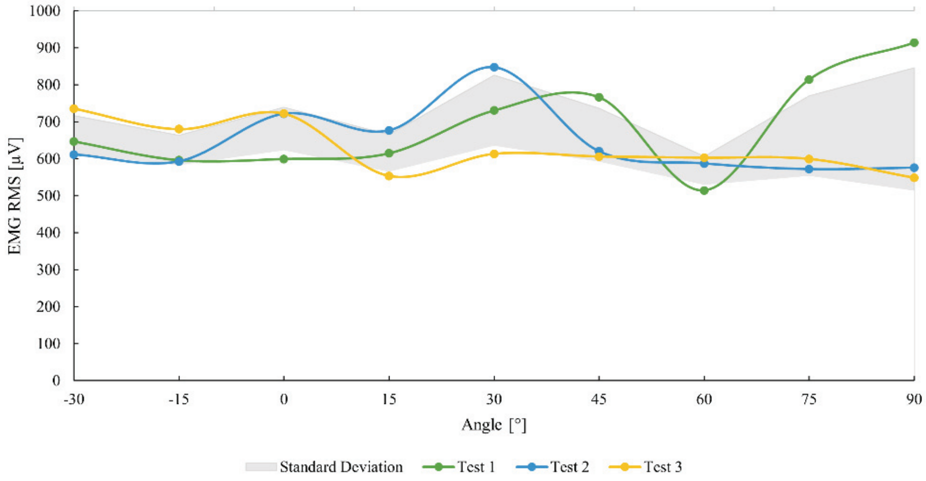
For the long head of the biceps muscle, in the case of bending in the shoulder joint, the angle selected for further examination is the angle of 75°, and for abduction in the shoulder joint, the angle of 90°. Internal rotation in the shoulder joint was omitted because the activation values of the long head during this task are more than twice lower than the activation values in the other two tasks for that head.

For the short head of the biceps muscle, the angle determined for further studies, characterized by the highest activity of the head, is the angle of 115° in flexion at the elbow joint.

## 3.2. Results for the triceps brachii muscle

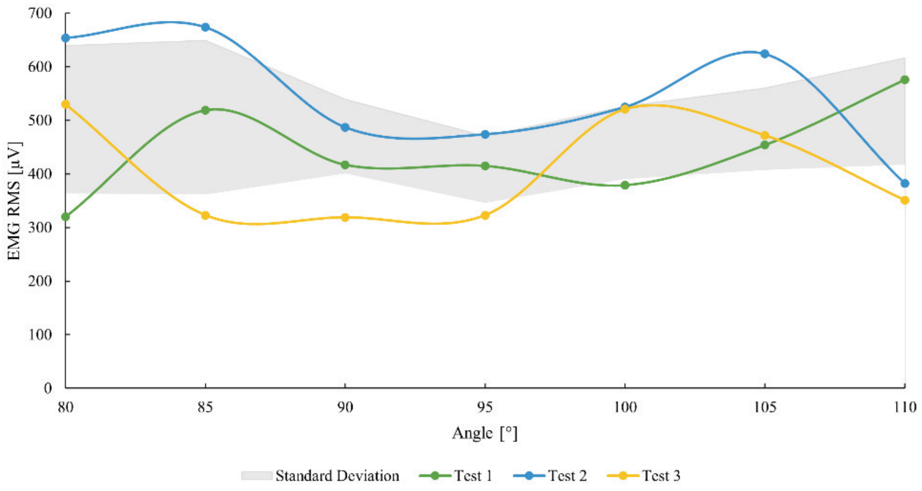
For the long head of the triceps muscle of the shoulder, the extension measurements in the shoulder joint were in the range of 614–730 μV (Fig. 14), and for the adduction in the brachial joint, this range was 408–517 μV (Fig. 15). There are no significant differences between the angles in these tasks.

For the lateral head of the triceps muscle, a growing trend can be observed, and the maximum activity



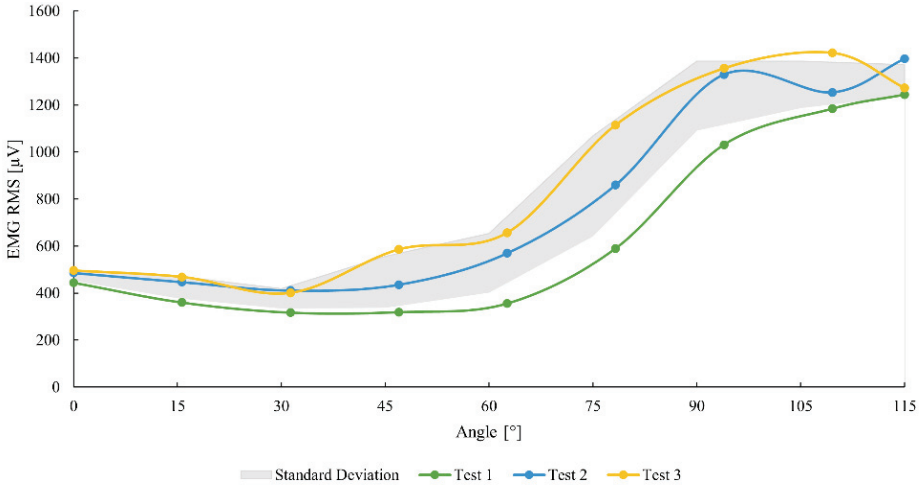
| Angle [°] | RMG RMS [μV] |
|---|---|
| –30 | 664.805 |
| –15 | 622.979 |
| 0 | 681.14 |
| 15 | 614.918 |
| 30 | 730.418 |
| 45 | 664.216 |
| 60 | 568.235 |
| 75 | 661.909 |
| 90 | 679.516 |

Fig. 14. Muscle activity as a function of angle for extension in the shoulder joint – the task of activating the long head of the triceps muscle of the shoulder



| Angle [°] | EMG RMS [µV] |
|---|---|
| 80 | 501.333 |
| 85 | 505.333 |
| 90 | 470 |
| 95 | 408.333 |
| 100 | 458 |
| 105 | 483.667 |
| 110 | 517 |

Fig. 15. Muscle activity as a function of the angle for adduction in the shoulder joint – the task of activating the long head of the triceps muscle of the shoulder



| Angle [°] | EMG RMS [µV] |
|---|---|
| 0 | 475.333 |
| 15 | 425.333 |
| 30 | 376.33 |
| 45 | 447 |
| 60 | 527.667 |
| 75 | 855 |
| 90 | 1239 |
| 105 | 1286.667 |
| 115 | 1304.667 |

Fig. 16. Muscle activity as a function of the angle of straightening in the elbow joint – the task of activating the lateral head of the triceps muscle of the shoulder

from the average of the three measurements is 1300 µV (Fig. 16).

The selected angle is 30° for shoulder extension and 110° for shoulder adduction.

For the lateral head of the triceps brachial muscle, measurements showed that the angle at which the lateral head is most activated is 115°.

## 3.3. Supplementary tests

On the basis of the measurements performed, cases were selected for further research in order to determine the desired parameters for Hill's constitutive model. The tests were aimed at determining the positions of the upper limb to maximally activate and isolate the individual heads of the biceps and triceps muscles. The obtained results prompted the conduct of supplementary measurements to check other limb positions, with the intention of achieving an even greater level of muscle activity, e.g., by combining/assembling two limb positions that maximally activate a given head of the muscle.

For the long head of the biceps brachial muscle, additional tests were carried out to check the intermediate position between the two strongly activating positions of the limb – the intermediate state between flexion and abduction in the shoulder joint (Fig. 17). The head was examined with the intention of achieving even greater activation. The measurement was carried out depending on the seven bending angles. The equipment and measurement conditions were the same as in the previous tests presented in Chapter 2.

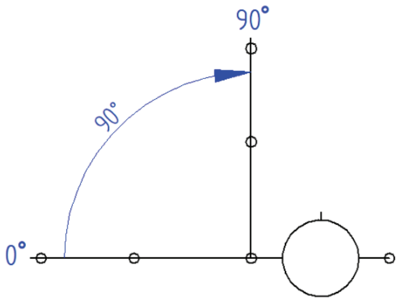


Fig. 17. Straightening in the shoulder joint (transverse plane)

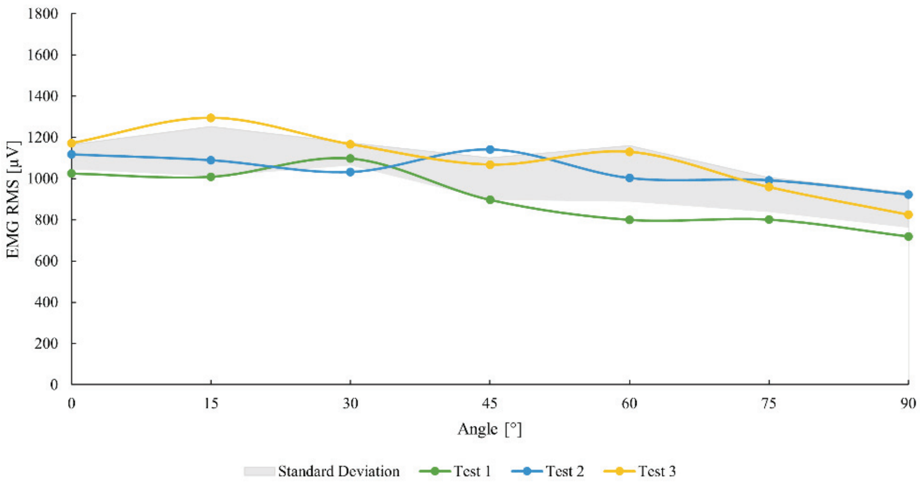
The list of tasks that activated the long head the most did not yield the expected results, and there was no increase in muscle activation (Fig. 18). The angle at which the greatest activity was recorded is the angle of 15°, where the activation level was 1131 µV. This is a decrease of about 22% compared to shoulder flexion and a decrease of about 27% for shoulder abduction. Consequently, the intermediate position between flexion and abduction in the shoulder joint is omitted in the following work steps.

The activity of the long head of the triceps muscle was characterized by almost twofold less activity compared to the other three analyzed muscle heads. The results provoked the willingness to conduct supplementary tests checking different positions of the limb, but after re-consultation with the physiotherapist, it was found that for the long head of the triceps muscle, there are no other tasks in which it is possible to isolate the examined head as much as possible other than by previously performed movements, i.e., straightening and adduction in the shoulder joint. The poses analyzed remain the positions in which the maximum activity of the long head of the triceps muscle can be tested.

# 4. Discussion

On the basis of the publicly available literature, no studies were found in which the positions of the musculoskeletal system were compared in order to determine the position of maximally activating individual muscles, taking their isolation from the given muscle group into account. We believe that such a study can give a more complete insight into the working of the muscle and is necessary to reliably determine the level of its activation.

As mentioned in the introduction to this paper, many studies on muscles use isometric contraction measurements for a variety of purposes. The predominant research is where the level of muscle activity is compared with strength, giving an answer to multiple questions. The study [2] investigated the relationship between EMG and the brachial static force of the biceps muscle with respect to the location of the EMG sensor. The electromyographic signal was normalized to the peak RMS EMG signal of isometric contraction performed at a 90° angle in the elbow joint at maximum level. Muscle activity was also recorded and analyzed for three different levels of generated strength. The research carried out in this way made it possible to understand the difference in the amplitude of the signals due to the placement of the sensors. The position of the upper limb has an influence on the level of activity and strength, in this case, the grip strength, which was checked to some extent in the study [44]. The muscular activity of five muscles was analyzed, including the biceps muscle during four different poses through two tests, where in the first of them the maximum grip strength and the corresponding EMG



| Angle [°] | EMG RMS [uV] |
|---|---|
| 0 | 1104.667 |
| 15 | **1131** |
| 30 | 1118 |
| 45 | 999 |
| 60 | 1023.667 |
| 75 | 921 |
| 90 | 845.3333 |

Fig. 18. Muscle activity as a function of angle for the intermediate position between flexion and abduction in the shoulder joint – the task of activating the long head of the biceps muscle

signals were recorded, and for the same poses – the EMG signal at the level of 10% of the maximum strength. In [41], the EMG signal was recorded during isometric contraction of the upper limb at the elbow angle of 60° for maximum effort and low strength. Here, these measurements, among others, made it possible to determine how exercise-induced muscle damage affects neuromuscular recruitment patterns. The study [1] compared the differences in the EMG activity of the upper limb muscles depending on age. Through RMS analysis, it was determined whether the EMG amplitude during voluntary isometric contraction decreased or increased with age. Recorded muscle activity during MVC was considered to be the value to which the EMG signal was normalized. The research carried out in this way made it possible to conclude that the age of young adults is an important factor determining the activity of the EMG signal of the biceps muscle, which can be used, inter alia, in ergonomics research.

As in the exemplary studies presented, muscle activity was compared to strength, where activity was related to a single muscle, while strength was recorded for a muscle group. It should also be noted that there is no protocol that unambiguously defines a thoroughly proven position that maximally activates the biceps and triceps muscles of the arm, additionally divided into surface heads. Moreover, the authors of individual works independently decide on the choice of the angle at which they conduct isometric contraction measurements, and usually it is one angle at which all measurements are carried out.

The study [17] investigated the influence of the joint angle of the upper limb at a given position on the relationship between the force and amplitude of the electromyogram for the biceps and triceps muscles. The EMG signal was measured at eight angles in the elbow joint during isometric flexion and extension at various levels of the MVC. The angle of the joint was found to have a significant influence on the MVC force, but the angle did not influence the EMG amplitude. In this paper, graphs of the EMG signal as a function of the flexion angle for the biceps muscle and as a function of extension for the triceps brachial muscle are presented, while the normalization of the signal was performed in relation to the value of the EMG signal occurring during the maximum MVC point. The normalization carried out in this way disqualifies the possibility of comparing with our measurements, which were expressed as the average of the number of trials, expressed in μV.

The authors [35] recorded the activity of the biceps brachii, among others, when measuring isometric contraction at the maximum voluntary MVC force for elbow flexion, at six elbow flexion angles. Despite the different aim of the research conducted by the authors, on the basis of the presented results in the form of a graph of muscle activity as a function of the flexion angle, we found the same results. The activity values of the biceps brachial muscle (not divided into heads) were read and estimated from the presented graph. The angles at which the isometric contraction was performed do not coincide with the values of the angles used in the present study, but the differences are slight. An approximate comparison of the results obtained with the study [35] was possible by presenting the muscle activity by the authors in the form of an average of the number of measurement attempts made, as shown in Fig. 19.

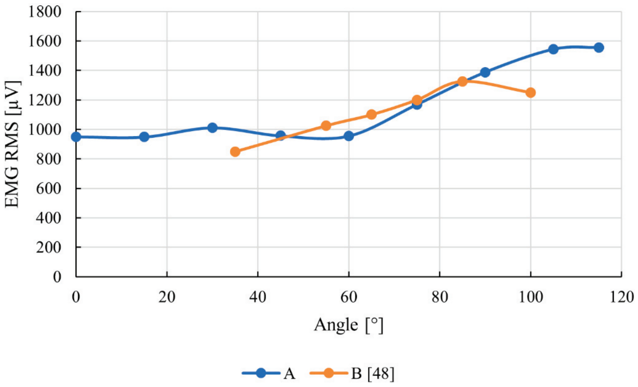


Fig. 19. Muscle activity as a function of angle for:
A) our research, B) the research carried out in [48] for bending in the shoulder joint – the task of activating the long head of the biceps muscle of the shoulder.
Activity expressed as an average value from

The results of the conducted research are largely in line with the results of the study [17] – an increase in the activity of the biceps muscle is observed with the increase in the flexion angle in the elbow joint. Due to the presentation of the results in μV, and not as a percentage related to the maximum activity value, we can compare the course of the measurements. The amplitude of surface EMG is influenced by many factors, such as: electrode location, electrode size, electrode movement, the metabolic state of the muscle, and the thickness of the subcutaneous tissue.

There are also studies where the patterns of muscle activity in the upper limb depending on the position of the forearm have been studied. In the work [9], EMG activity of the biceps and triceps muscles of the arm was recorded during isometric contraction during flexion – extension in the elbow joint, with the imposition of the task of supination – pronation of the forearm. The authors' conclusions indicate a significant increase in the activity of the biceps muscle by superimposing supination on the flexion, while the triceps muscle of the shoulder was characterized by signal modulation both with supination and pronation, despite the fact that it does not have a mechanical role in this positioning. The study [42] compared two different modes of maximal voluntary isometric MVC contractions – against manual resistance and against fixed cranks – specific for sport. For the triceps muscle, the MVC was higher in the case of sport-specific tasks, thus defining them as appropriate for this muscle, while for the biceps muscle, the tasks in manual resistance – elbow flexion at an angle of 90°, proved to be better. The study [30] aimed to investigate the role of each of the heads of the triceps brachial muscle in relation to the shoulder elevation angle. Each head has been found to have different activity during different shoulder lifts. The long head contributes to the greater extension of the elbow when the shoulder is lifted, while the medial head takes over the movement at an angle of 90° and above. For muscle modeling purposes, the EMG of the biceps muscle and the angle of the elbow was examined in [34]. This study also did not find significant changes in EMG amplitudes depending on the angle of the joint.

# 5. Conclusions

The cited articles were intended to illustrate the incomplete connection of the available studies with the presented research.

The aim of this publication was to determine which tasks are most likely to cause the greatest stimulation of the individual heads of the biceps and triceps muscles.

The performed tests can also be a preliminary assessment of the upper limb positions, for which wider conclusions could be drawn in the case of measurements on a larger number of participants.

The next stage of experimental research will consist of repeated measurements of isometric contraction for selected limb positions and flexion angles as well as upper limb movement tests. Static measurements were carried out to determine the maximum values of the moments of force for individual muscle heads. Dynamic measurements will enable the determination of activity curves during the movement of the upper limb. Measurements are an essential part of the work, the end result of which will be the determination of parameters for the Hill constitutive model, such as maximum isometric force and activity curve during flexion-extension movement in the elbow joint. The combination of the planned experimental studies with the already conducted magnetic resonance imaging will enable preliminary numerical analyses using the finite element method. The developed model of the upper limb is to be used to reproduce using the flexion-extension movement performed at the elbow joint computer simulation, taking muscle–muscle, muscle–bone interactions into account. Numerical muscle models will consist of passive and active parts as described by Hill's model.

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