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Original paper

# Asymmetry of electromechanical delay (EMD) and torque in the muscles stabilizing spinal column

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Stabilization of the spinal column is ensured by the activity of trunk flexor and erector muscles, including rectus abdominis (RA) and erector spinae (ES). The goal of this study was to evaluate the symmetry of action potential and electromechanical delay (EMD) in RA and ES during generation of maximal muscle torque. In the present study, the symmetry of EMG activity in the right and left parts of RA and ES was tested under isometric conditions. The subjects ($N = 13$) were selected from the university population. Electromyographic signals and muscles torques were recorded with the sampling frequency of 1000 Hz. Lack of significant differences in EMD between left and right sides in both muscles studied and lack of correlation between EMD and maximal muscle torque were observed. Analysis aimed at assessing the symmetry of EMG signals amplitude revealed crossed laterality characterized by increased activity in the right side of RA muscle and left side of ES. The proportion of maximal muscle torque in ES to RA in the women examined amounted to 1.7:1.

*Key words*: *back stability, electromechanical delay* (*EMD*), *EMG, asymmetry*

## 1. Introduction

Scientific research works have reported a low back pain (LBP) syndrome in 50% of professionally active adults [1]. One of the reasons for low back pain lies in the disturbed (improper) stabilization functions in trunk muscles. Physiological spinal curvature in sagittal and frontal planes is ensured by spinal flexor and erector muscles. A characteristic feature of these two groups of muscles is their symmetrical location on both sides of spinal column. As shown by the study, the asymmetry of EMG activity in both back and abdominal muscles occurs during both maximal voluntary contraction (MVC) and functional activity. This results from dynamic asymmetry, which manifests itself as different values of muscle torque in right and left parts of human body caused by left-sided or right-sided laterality [2]. Regardless of the existing asymmetry of EMG activity in trunk flexor and erector muscles, no disturbances in spinal static behaviour have been reported. Different coordination of excitation of the muscles which stabilize the spinal column may compensate for the asymmetry of the EMG action potential. The essential role of time characteristics of EMG signals in coordination of spinal column stability was reported in the investigations presented by NORRIS [3]. There are a variety of temporal parameters of EMG signal which define intramuscular coordination. One of them is electromechanical delay.

Electromechanical delay (EMD) is defined as a time between the onset of electrical activation of the muscle and the onset of force development. The duration of this onset in skeletal muscles ranges from 26 to 131 ms [4]. EMD has been reported to be affected by a number of structures and mechanisms such as: (1) the propagation of the action potential in muscle membrane with time, (2) extraction–contraction cycle,

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and (3) the stretching of the series elastic component (SEC) by the contractile element. However, the time taken to stretch the muscle–tendon unit in vivo is considered to account for the main part of an EMD value [5]. A few studies have reported the differences in EMD due to gender [6], age [7], the type of muscular activity [6], initial muscle length at which EMD is measured [8]. Muscle fatigue [9] and immobilisation [10] also affect EMD.

Electromechanical delay can change with different types of physical exercise. KUBO et al. [11] reported a decrease in EMD after isometric training, but ZHOU et al. [9] found no changes in EMD following sprint training. Similarly, HAKKINEN and KOMI [12] reported no significant differences in EMD values calculated under reflex contraction before and after 16 weeks of strength training. GROSSET et al. [13] compared the chronic effects of endurance and plyometric training on the EMD and reported a strong, inverse relationship between the EMD and musculotendinous stiffness. These authors revealed increases in musculotendinous stiffness and decreases in the EMD whereas the plyometric training program elicited decreases in musculotendinous stiffness along with increases in EMD.

There have also been studies in which EMD was investigated through animal testing [14]. Data from animal experiments have documented the changes in stiffness due to training. Endurance training increased the stiffness of the SEC of the soleus muscle in rats and was associated with an increase in muscle type I fibre content [14]. The opposite results (i.e. an increase in fast twitch fibre content and a decrease in the SEC stiffness) were obtained for rats submitted to plyometric training [15].

The review of the literature on the subject indicates that there is lack of studies which would take into consideration the EMD phenomenon during analysis of symmetry of muscular activity in the muscles which stabilize the spinal column. The symmetry of action potential in these muscles seems to be essential for proper statics of the spinal column. Different time pattern for exciting both muscle erector spinae (ES) and rectus abdominis (RA) is expected to compensated for lack of the symmetry of action potential for the right and left parts of these muscles. Therefore, the study was undertaken in order to assess the degree of the symmetry of bioelectrical activity in the muscles which stabilize the spinal column under static conditions. This assessment was performed based on the analysis of EMG signals in the consideration of action potential and electromechanical delay (EMD).

# 2. Methods

## 2.1. Experimental procedures

The study covered 13 volunteer right-handed female students from the Faculty of Physical Education (mean height: 168.5 cm, mean weight: 55.5 kg). To ensure the highest possible representativeness of the results obtained, persons of the same gender were selected (females) with similar age range (21–25 years), similar level of physical activity and body type. All the subjects were informed about the goal of the experiment and gave their written consent to be tested. The experiment was carried out on the basis of the approval given by the Ethical Commission for Scientific Research of the University School of Physical Education in Wrocław.

For the purposes of the present study, it was also necessary to make use of the surface EMG method and the method of measuring muscle torques under static conditions in order to register and analyse EMD. Both signals were measured during the experiment according to the principles in the subject literature [16], [17].

Measurements of muscle torques under static conditions taken simultaneously with recording of EMG signals were performed for the muscles which are numbered among a group of hip-joint trunk flexor and erector muscles, i.e. rectus abdominis (RA) and erector spinae (ES).

Surface electrodes were located on the right and left sides of ES and RA. Additional electrodes were attached to RA in its upper and lower parts (figure 1).

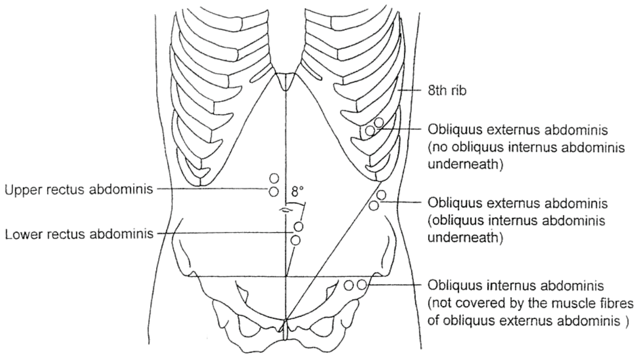


Fig. 1. Layout of electrodes in rectus abdominis (after NG et al. [22])

The choice of right/left and upper/lower parts of the RA for EMG analysis results from the specific structure of this muscle. Similar approaches to investigating the activity of this muscle have been adopted by other authors [18]–[20].

*Surface electrodes were placed on ES, two fingers in width, laterally with respect to the processus spinosus of L1 in vertical orientation [16].*

Surface electrodes were located according to the principles of the best reception of the EMG signal given in the literature on the subject [16], [18], [21], [22] and based on the location of muscles, when individual anatomical build of the persons examined is taken into account.

During the experiment, action potential in the muscles was recorded by means of solid gel surface electrodes (Ag/AgCl by NORAXON Inc.). Surface electrodes were arranged in bipolar configuration on the bellies of the muscles, along the muscle fibres. The set comprised 6 pairs of active electrodes and one reference electrode located on the skin surface in electrically passive places (anterior superior iliac spine).

In order to pick up the EMG signal, Octopus eight-channel electromyograph (Bortec Electronics Inc., Calgary, Alberta; CA) was employed. Sampling frequency of the registered signals amounted to 1000 Hz.

The study was performed in the Biomechanical Analysis Laboratory of the Department of Biomechanics at the University School of Physical Education in Wroclaw (PN-EN ISO 9001:2001).

## 2.2. Experiment structure

The subjects examined were asked to develop, after a particular signal under static conditions, maximal muscle torque.

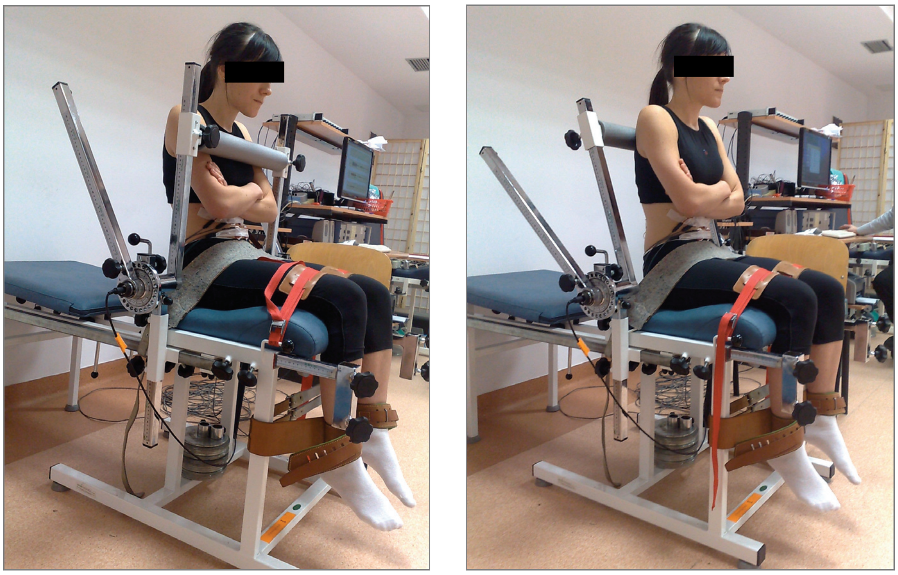
Measurements were taken in sitting position in a multi-functional SUMER Opole (UPR-01 A/S) armchair (figure 2).

For the purposes of the experiments, the armchair was overhauled. The modification consisted in connecting another torque meter to the previous one, both being connected to a transverse bar in order to force symmetrical pressure of the examined person on measuring head during development of maximal muscle torque. Technical characteristics of the measuring device can be described by the following features:

- torque meter: strain gauge head – measuring range of 0÷500 Nm, relative error in strain-gauge bridge amounts to 0.5%,
- direct current amplifier with calibrated amplification of $k = 470$, bandwidth: 0÷1 kHz, zero drift: 0.6 μV/°C.

Measurements of muscle torque were performed in a multi-function armchair, according to the generally accepted principles [17]. The persons examined were sitting in the measuring stand. The angle at hip and knee joints was determined as 90°. According to the adopted principles, the axis of hip joint was in line with the axis of the dynamometer. In order to eliminate the effect of other muscle groups on the measurements through the so-called muscle transfer, upper extremities were crossed in the area of chest, whereas pelvis, thighs and shanks in the area of ankle joints were immobilized by stabilizing belts (figure 2).

The resistance part of the measuring stand was placed:



a) b)

Fig. 2. Position of the person examined in the measuring stand:
a) measurement of muscle torque and electrical activity in RA; b) measurement of torque and electrical activity in ES

- at the front, in the thorax area – during measurement of EMG and muscle torque in rectus abdominis (figure 2a),
- at the back of the trunk, in the scapula area – during measurement of EMG and muscle torque in erector spinae (figure 2b).

The length of the external lever arm during each measurement was selected individually in the consideration of an anatomical build of the persons examined. This approach remains consistent with the generally accepted principles of measurement of muscle torque under static conditions [17].

**EMG signal processing.** Raw EMG signal and muscle torque were registered in a personal computer and recorded by means of BioWare software. The onset of muscular activity and the onset of force development were determined by means of two-stage method of detecting the activity in EMG signal and muscle torque [23]. This method is based on the analysis of the differences in signal strength between the part of the signal which precedes the activity and the part where the activity occurs. The analysis was carried out on the non-filtered signal. During the first stage, each measuring point was assigned a probability of being the initial moment of activity, whereas during the second stage, the initial point of activity was chosen from the area for which the estimated probability was the highest (figure 3). This method allowed for avoiding phase lags which are typical of one-way filtering.

The algorithm used in this work can be described as follows:

Step 1. For each time step calculate differences between standard deviations for the left part of the signal and the right part of the signal.

Step 2. Normalize values of resulting signal to the range [0, 1]. Let us call this signal *the difference function*.

Step 3. Select the value of a parameter from the range of $\beta \in [0, 1]$.

Step 4. Take the first time step, for which the *difference function* has a value equal to $\beta$, as the first approximation of the moment of muscle activity.

Step 5. Select the value of a parameter $\varepsilon \in \mathcal{R}$.

Step 6. Step back until difference between values of the *difference function* for neighbouring time steps is greater than $\varepsilon$.

In this work, we used $\beta = 0.8$ and $\varepsilon = 0.0001$.

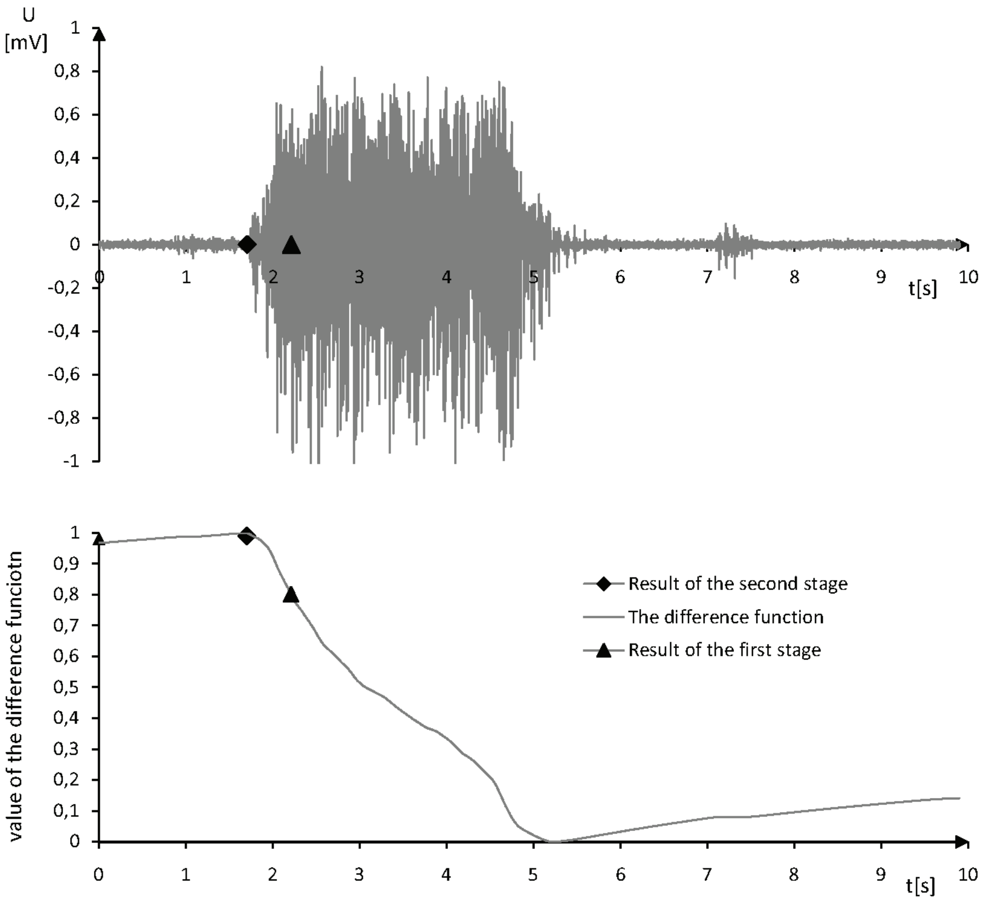


Fig. 3. Two-stage activity detection method

The algorithm described above was employed to detect the onset of activity in the EMG signal as well as the onset of the muscle torque development.

# 3.Results

## 3.1. Evaluation of the symmetry of action potential

Table 1 compares mean values and standard deviations for the amplitude of action potential in the muscles studied during maximal voluntary contraction.

The conducted statistical analysis using Student's *t*-test for independent data revealed statistically significant differences between left and right sides in the amplitude of EMG signal in RA only in its upper part (*t*-value = 2.039, for *df* = 28, *p*-value = 0.05) with the dominance of the right side. EMG activity in ES was also characterized by a significant difference between left and right sides (*t*-value = –3.299, for *df* = 28, *p*-value = 0.0026); however, left-sided activity dominated in this case.

During the experiment, the EMG signal was not normalized to obtain the value of maximal voluntary isometric contraction (MVIC). The signal should be normalized if the activities in different muscles in different motor tasks are compared. Since humans are characterized by dynamic asymmetry, manifested itself as the difference between forces in right and left sides of the body, one can assume that the asymmetry also concerns the EMG activity. If the values of the EMG signal are related to normalized values, the possible differences between the activity in right and left muscles would not be observed. Similar approach to the analysis of EMG signal in the muscles of right and left sides of the body has been reported by other authors [24].

## 3.2. Assessment of the symmetry of electromechanical delay (EMD)

Table 2 presents mean values and standard deviations for EMD in the muscles studied.

The statistical analysis of EMD reveals lack of significance in mean differences in the studied case for both muscles (table 2).

## 3.3. Effect of parameters of EMG signal and muscle torque

During the experiments, the values of the developed muscle torques in the muscle groups were also measured. The resultant muscle torques in RA and ES reached 130.62 Nm and 222.78 Nm, respectively. The

Table 1. Mean values, standard deviations for the amplitude of EMG signal in the muscles studied, *t*-values, degrees of freedom (*df*) and level of probability (*p*-value) for the Student's *t*-test

| Muscles | | | EMG signal amplitude (mV) | Student's *t*-test | *df* | *p*-value |
|---|---|---|---|---|---|---|
| Rectus abdominis (RA) | Upper part | Right side | 0.708±0.43 | 2.039 | 28 | 0.050 |
| | | Left side | 0.638±0.34* | | | |
| | Lower part | Right side | 0.468±0.19 | 0.887 | 28 | 0.382 |
| | | Left side | 0.444±0.18 | | | |
| Erector spinae (ES) | Right side | | 0.417±0.17 | –3.299 | 28 | 0.0026 |
| | Left side | | 0.494±0.21* | | | |

* Significance level $p < 0.05$.

Table 2. Mean values, standard deviations for EMD in the values studied, *t*-values, degrees of freedom (*df*) and level of probability (*p*-value) for the Student's *t*-test

| Muscles | | | EMD (s) | Student's *t*-test | *df* | *p*-value |
|---|---|---|---|---|---|---|
| Rectus abdominis (RA) | Upper part | Right side | 0.064±0.038 | 0.108 | 18 | 0.915 |
| | | Left side | 0.063±0.036 | | | |
| | Lower part | Right side | 0.062±0.033 | –0.454 | 23 | 0.653 |
| | | Left side | 0.064±0.037 | | | |
| Erector spinae (ES) | Right side | | 0.090±0.044 | 0.561 | 15 | 0.58 |
| | Left side | | 0.083±0.048 | | | |

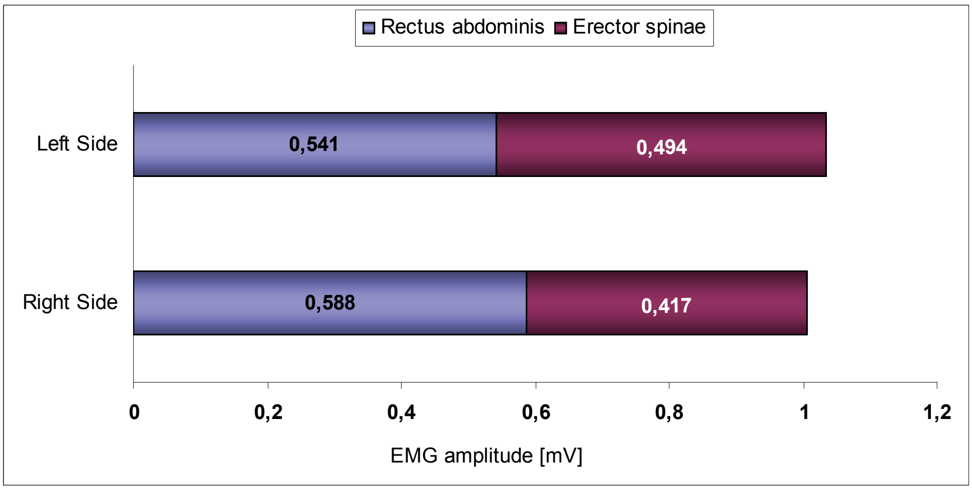


Fig. 4. Mean values for the EMG signal in the muscles on the right and left sides of the body

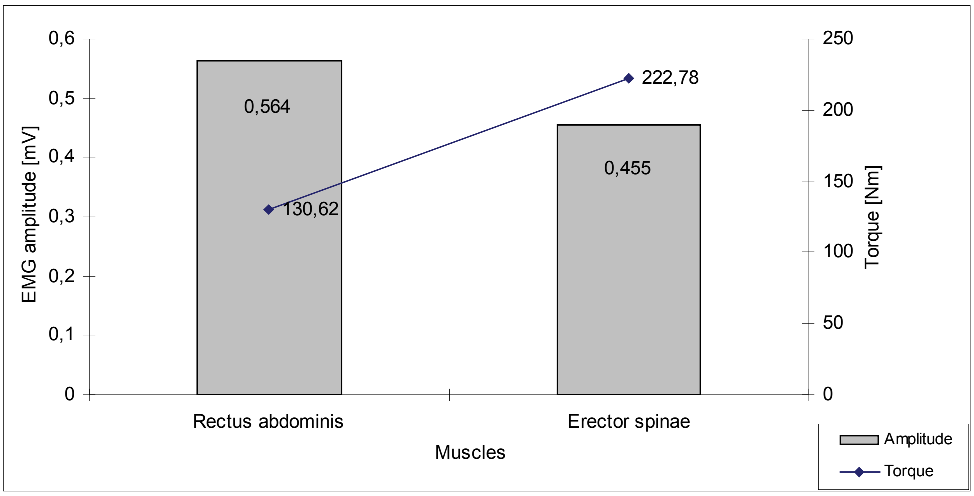


Fig. 5. Sum of action potential in the muscles vs. resultant muscle torque

differences between mean values of muscle torque turned out to be statistically significant, which was proved by the results of the test $t = -5.753$ at $df = 56$ and $p = 0.0001$. The analysis of the relation between the muscle torques in flexors and erectors revealed that the resultant muscle torque in trunk erectors exceeded the muscle torque in trunk flexors by 70%. The ratio of the maximal muscle torque in trunk erectors to trunk flexors thus amounts to 1.7:1.

Another stage of this study involved determining the proportion of action potential in the muscles on the right and left sides. The study revealed that EMG activity in RA is by 8% higher on the right side, whereas the amplitude in the ES is by 15.5% higher on its left side (figure 4). The analysis of the functions performed by the studied muscles in relation to each other proved that the signal amplitude of RA (flexor) was by 29% higher on the right side compared to that on the right side of its antagonist. EMG signal analysis on the left side showed similar relationship: RA muscle also dominated in this case, however, by merely 9% (figure 4).

During the next stage of the analysis, action potential was totalled for both sides of the muscles studied. The level of their involvement versus the muscle torques was compared in figure 5.

At this stage of the investigations, the correlation of the combined amplitude of the EMG signal with muscle torque in the muscles studied was analysed. The results of the analysis revealed the relationships between these values only for ES ($r = 0.39$, $p$-value $= 0.035$).

The analysis of the correlation between EMD and the muscle torque developed did not reveal any relationship between EMD and muscle torque in the muscles studied.

# 4. Discussion

Humans are asymmetrical by nature. One of the symptoms of asymmetry is *dynamic* asymmetry, which manifests itself, among other things, as different opportunities to generate force by, e.g., right and left upper or lower extremity. Dynamic asymmetry evaluated by measuring muscle torques was reported in both children and adults [25]. One can assume that when considering the stabilization function of the spine, the right and left parts of flexor and erector muscles in healthy persons should be characterized by symmetrical activity during development of muscle torque. Since measurement of muscle torque is the resultant of the activity in left and right parts of the muscle, an electromyographic method was employed to assess the symmetry of activity in these muscles. Stabilization of the spinal column is ensured by the back and abdominal muscles. This study covers the analysis of the activity of the muscles which, under standard conditions, fulfil motor functions, whereas stabilization functions are performed under conditions of maximal force development. Therefore, it was assumed that during maximal static exertion, the activity of RA and ES should be characterized by symmetry in the right and left parts of these muscles. The statistical analysis revealed the asymmetry in the amplitude of EMG signal both in RA and ES. Furthermore, higher activity in RA muscle on the right side and higher activity in ES muscle on the left side were also reported. Therefore, one can assume the occurrence of the so-called crossed laterality. Another characteristics of activity in these muscles (the symmetry in RA combined with the asymmetry in ES) was obtained in a study where muscle activity under static conditions was analysed, but the muscles were not forced to generate maximal force [26]. The asymmetry of the back muscles was also reported during investigations on EMG activity in muscle erector spinae and muscle trapezius [27]. The authors demonstrated the dominance of electrical activity in the right part of the muscles studied. However, AXLER and MCGILL [20] revealed the asymmetry of the activity in RA, which was characterized by the dominance of the left side over the right one.

It could have been assumed that the asymmetry in maximal action potential in the right and left parts of the muscles studied would be connected with the asymmetry of electromechanical delay. In the present study, no temporal differences were observed between electrical excitation of the muscles and the onset of force development between the right and left parts, both in RA and ES. Lack of correlation between the time of electromechanical delay and maximal muscle torque was also reported. But on the other hand, DIEEN et al. [28] proved that maximal muscle torque and endurance time are significantly correlated with EMD. These authors investigated the phenomenon of EMD for the ES in terms of the effect of the rate of force development, fatigue and location of surface electrodes which registered action potential.

The dominance of muscle torque values in trunk erectors over trunk flexors was observed in the present study, with reverse relationships found for action potential in the muscles included in these muscle groups. This might prove that RA is the muscle which generates the maximal muscle torque in trunk flexors, whereas during the development of maximal muscle torque for erector muscles, a significant contribution is due to functional units of the erector spinae, which were not covered by this study.

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