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Influence of type of MVC test on electromyography measures of biceps brachii and triceps brachii

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Objective. This study aimed to investigate the amplitude and frequency measures of the electromyography (EMG) signal in agonistic and antagonistic muscles (biceps brachii, triceps brachii). *Methods*. Fifteen males (22.9 ± 2.1 years old) took three isometric maximum voluntary contraction (MVC) tests. Two tests were typical MVC tests for biceps brachii and triceps brachii. The third was a test often used to obtain MVC for forearm muscles (arm and forearm hanging down). The EMG signal was recorded during three isometric MVC muscle contractions and during a relaxation test. *Results*. There were no differences in amplitude between relaxation and MVC antagonist in static contraction, with higher values for frequency measures in relaxation. When biceps brachii and triceps brachii act as antagonists in an MVC test, frequency measures present lower values than when the muscles act as agonists. Biceps brachii shows much lower amplitude than during an agonist MVC contraction with similar spectral measures. Triceps brachii presents much higher values of spectral measures than during an agonist MVC test. *Conclusion*. The type of exerted force, i.e., if a muscle acted as an agonist, antagonist or stabilizer, affects the relationship between the time and frequency domain measures.

Keywords: maximum force capabilities; muscle relaxation; peak frequency; power spectrum; time and frequency domain

1. Introduction

Phenomena related to muscle contraction can be registered by electromyography (EMG) with electrodes inserted into a muscle or placed on the skin surface over the muscle. Mostly because it is non-invasive, EMG with surface electrodes is increasingly significant in various applications. Measurements of the EMG signal and analyses of the differences in EMG measures are frequently used in analysing the level of muscle contraction [1,2] or fatigue [3,4]. EMG is also applied to investigate muscle activity during physical exercises [5] or to diagnose the relationship between muscle cramp and exercise-related pain [6].

Measures of the EMG signal are usually calculated on the basis of an analysis done in terms of either time or frequency represented by the amplitude and the power spectrum of the signal, respectively. Of the various measures of the power spectrum, median frequency (MF) and mean power frequency (MPF) are especially useful [1,7]. Other measures of the power spectrum that convey crucial information are, e.g., the first and third quartiles, standard deviation and skewness [8] and bands of the power spectrum [9,10].

The level of muscle contraction, which is related to muscle force, is an influential factor; it determines both amplitude and frequency measures [1,2]. Muscle contraction is usually a result of normalization and expresses the percentage of maximum voluntary contraction (MVC). MVCs represent the maximum voluntary isometric activation of a muscle and provide a physiological reference point. Normalization of the respective EMG signal is usually based on measurements during MVC. However, in some normalization procedures, a signal registered when posture is sustained without an external force, i.e., during muscle relaxation, is used as a baseline signal. It is subtracted from both registered and referenced contraction signals. However, it is also applied as a reference signal of testing for patients with neurological dysfunction, such as cerebral palsy or stroke, and also for testing elderly people and those with osteoporosis [11].

Muscles can act as agonists or antagonists depending on the exerted external force. Some muscles stabilize a given posture when external force is exerted by other muscles, e.g., when handgrip force is exerted, arm muscles stabilize the upper limb posture. MVC tests are performed in specific force activities to produce maximum force in an agonistic muscle [10]. However, in addition to the tested muscles, other muscles, including antagonistic ones, are also activated during those tests. It can be supposed that antagonistic muscles in isometric conditions can be relaxed. A question arises if antagonistic muscles have the same characteristics in time and frequency domains like muscles during relaxation. When considering arm muscles,

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biceps brachii (BB) produces flexion at the elbow. Triceps brachii (TB) extends the elbow. TB is, therefore, an antagonist of BB in flexion. BB is an antagonist of TB in elbow extension.

When an EMG signal for normalization purposes is detected, a muscle can act differently in MVC conditions than when it is activated during proper tests. It can be then supposed that a different force type can determine the characteristics of the EMG signal in the frequency domain.

The objective of this study was to investigate the relationship between amplitude and frequency measures of the EMG signal in agonistic and antagonistic muscles of the arm during different MVC tests. This study was to answer the following questions: are there differences in amplitude and frequency measures between relaxation and MVC when BB and TB act as antagonists in static contraction; are frequency measures for BB and TB obtained during MVC measurements different depending on whether those muscles act as agonists or antagonists; do BB and TB differ in terms of amplitude and frequency measures when they act as stabilizers during handgrip force?

2. Methods

Fifteen healthy young adult males were recruited to participate in this study. Their mean $\pm$ standard deviation age, weight and height were, respectively, 22.9 ± 2.14 years, 72 ± 6.11 kg and 182.67 ± 3.38 cm. The participants reported no history of shoulder or upper limb pain or injury. All of them were right-handed. After being informed of the purpose and the protocol of the experiment, the participants signed a written consent form. The study protocol was approved by the local ethics committee and was performed according to the Declaration of Helsinki. The body mass index (BMI) was calculated for each participant and was between 18.5 and 25, i.e., the ratio of weight to height was normal.

The experimental protocol consisted of a preparatory phase and an experimental phase. During the former, the skin, shaved if necessary, at each electrode site was carefully abraded and cleaned with alcohol. If the skin–electrode impedance was too high, this was signalled by the EMG measurement system. Measurements were done with surface electrodes placed on the skin over the muscle belly, longitudinally to muscle fibres. The electrodes were placed on the medial head of BB and the lateral head of TB, halfway between the probable location of the tendons. When the electrodes were attached, the participant was asked to relax and activate muscles to provide information on the differences between signal and noise. The differences in the amplitude of those signals were checked visually. If they were not satisfactory, the location of the electrodes was improved.

In the experimental phase, the participants completed three isometric MVC tests, each of which was repeated twice. Two tests were typical for each muscle (MVC-BBt and MVC-TBt). The third was a test often used to obtain MVC for forearm muscles (MVC-fore). The participants were instructed to maintain maximum force for 3 s. A 2-min rest was allowed between each 3-s isometric muscle action. To avoid the potential effect of fatigue, the order of the tests was randomized.

To generate MVC for BB and TB, the shoulder and elbow were maintained at 90°, while manual resistance was applied at the forearm in the direction towards the body (BB MVC) and away from the body (TB MVC). The participant's forearm was in a neutral position. The possible influence of gravity was ruled out by having the upper limb resting on a support. Testing, which activated mostly the muscles of the forearm, was done with a hand dynamometer (JBA Zb. Staniak, Poland) squeezed in the hand. During this test, the arm and the forearm were hanging down.

The EMG signal was recorded with double-differential surface electrodes DE-3.1 (Delsys, USA). The distance between the three electrodes was $\sim$10 mm. The EMG signal was measured with a Bagnoli-16 (Delsys, USA) device with a bandwidth of 20–450 Hz ($\pm$10%). Bandwidth roll-off was 80 dB/decade, overall noise was $\leq 1.2\,\mu$V and EMG amplification was 1000. This apparatus, in conjunction with a computer, registered a raw EMG signal with a sampling frequency of 4 kHz.

Pushing, pulling and handgrip force were measured with a force sensor in conjunction with an appropriate converter connected to the computer with CPS version 2.0 to visualize the force. Different sensors were used for pushing, pulling and handgrip. Handgrip force was exerted on a hand dynamometer with a nominal measurement range up to 1200 N. The nominal measurement range of force for arm force was up to 2000 N. Measurements were done with a sampling frequency of 100 Hz, with maximal non-linear error $< 0.5\%$ and noise level $< 0.2\%$.

Measures characterizing the EMG signal in the time and frequency domains were determined on the basis of the signal recorded in a total of four tests (Rel, MVC-BBt, MVC-TBt, MVC-fore). To compute the measures, selected fragments of the EMG signal were divided into 1-s windows (boxcar windows; 50% overlap). The measures were calculated from each window. In the time domain, the EMG signal was described with root-mean-square (RMS) amplitude. MF and MPF, two parameters characteristic for the EMG signal in the frequency domain, were calculated with fast Fourier transform. Other parameters that describe the power spectrum of the EMG signal, i.e., the frequency of peak (Pf) and the border frequency of the spectrum (Bf), were also considered in the analysis of the EMG signal. Before Bf was determined, the power spectrum of the EMG signal was normalized by dividing each sample by the sum of all samples from the power spectrum. Bf is the highest frequency of the power representing the sample for which the normalized value equals 0.01.

The values of the RMS amplitude and EMG spectral measures were calculated for all muscle actions in each test: 1.5-s fragments of MVC with the most stable muscle contraction level (RMS) were analysed. This resulted in three samples for each measurement in the MVC tests. Six samples were recorded for relaxation. Values of EMG measures were normalized to the first sample obtained during the MVC test for the respective muscle (Figure 1). This resulted in normalized data of five parameters (nRMS, nMF, nMPF, nPf, nBf) for four tests (BB MVC, TB MVC, MVC-fore, Rel).

Data obtained in this way were further statistically analysed. The first step was to search for differences in measures between samples obtained during the first and second measurements of MVC. In the analysis, the differences between the two measurements of MVC were tested with the Wilcoxon sign-rank test. Because this analysis did not show any differences, data from the two measurements were pooled for further analysis. Separate one-way Friedman analysis of variance (ANOVA) and *post-hoc* comparisons were performed on EMG measures to determine whether there were significant differences between tests for both muscles.

3. Results

Table 1 presents force values measured for each participant during each test and each measurement. Statistical analyses did not show any differences between the two measurements in any of the analysed measures.

Figure 2 shows normalized values of EMG measures obtained in MVC tests and during relaxation in the two upper limb postures for BB (Figure 2a) and TB (Figure 2b).

The results showed strong differences not only in nRMS but also in spectral measures. Normalized EMG variables obtained during MVC tests from agonist muscles were close to 1, e.g., MVC-BBt for BB and MVC-TBt for TB. In MVC-TBt for BB, the value of nRMS was below 0.1 and the spectral measures (nMF and nPf) were close to 0.5. However, nBf exceeded 1. When measures obtained during muscle relaxation were considered, three out of four spectral measures (nMPF, nMF and nBf) were about 50% higher than the values obtained during MVC. nRMS during relaxation did not differ from the values obtained during MVC for an antagonistic muscle.

One-way Friedman ANOVA demonstrated statistically significant differences in all five measures. Table 2 presents

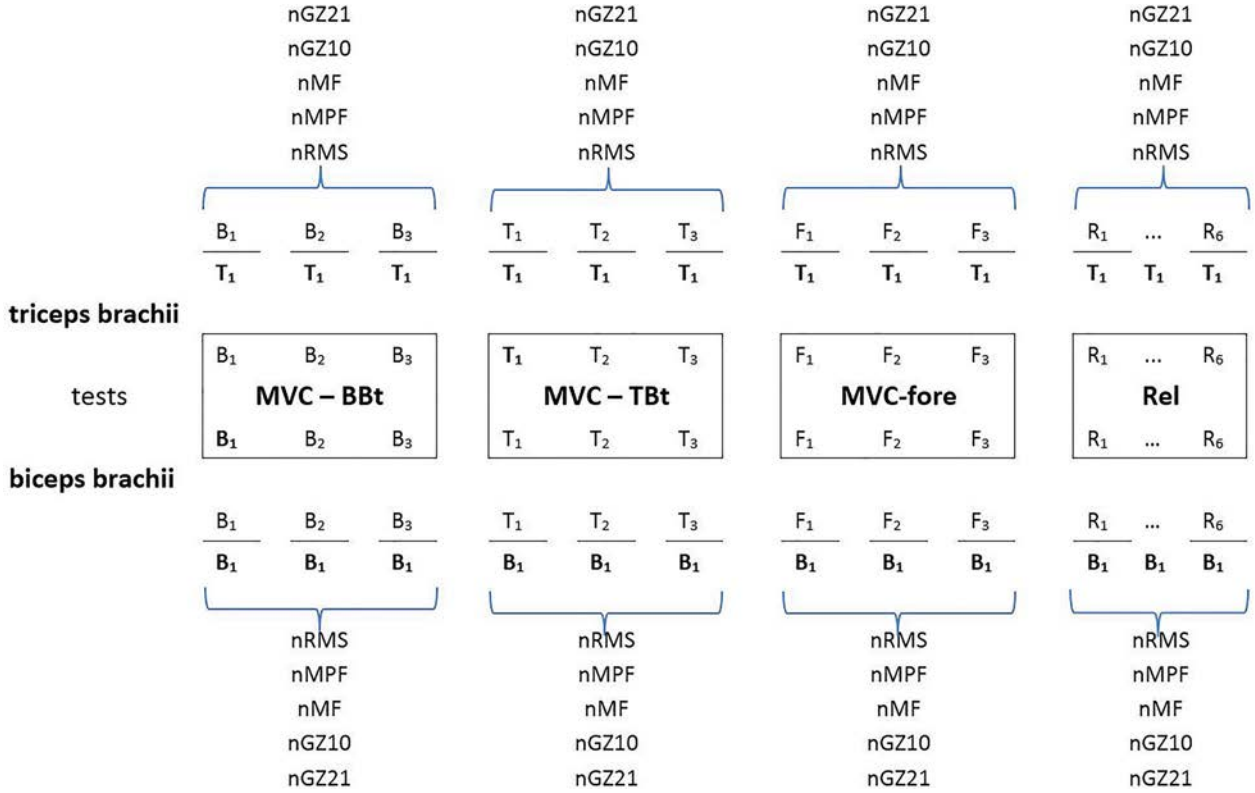

Figure 1. Illustration of the concept for analysis of the results.
Note: B = electromyography (EMG) signal parameters obtained during MVC-BBt; F = EMG signal parameters obtained during MVC-fore; MVC-BBt = test of maximum voluntary contraction for biceps brachii (BB); MVC-fore = test of maximum voluntary contraction for forearm muscles; MVC-TBt = test of maximum voluntary contraction for triceps brachii (TB); nMF = normalized median frequency; nMPF = normalized mean power frequency; nRMS = normalized amplitude of root mean square; R = EMG signal parameters obtained during test Rel; Rel = relaxation in the same upper limb posture as during MVC-BBt and MVC-TBt; T = EMG signal parameters obtained during MVC-TBt.

Table 1. Force capabilities measured for each participant during each test.

	MVC-fore (N)		MVC-BBt (N)		MVC-TBt (N)	
Participant	1	2	1	2	1	2
1	526	548	380	357	238	237
2	442	430	291	276	166	163
3	430	529	323	327	248	239
4	446	458	306	293	189	181
5	499	515	357	353	219	231
6	608	668	357	380	237	222
7	491	494	276	262	117	131
8	420	488	247	264	148	150
9	454	506	239	248	147	143
10	533	533	273	281	165	167
11	543	488	379	363	237	237
12	454	520	276	278	139	139
13	552	502	295	278	153	165
14	287	314	310	283	155	149
15	416	461	350	350	220	231

Note: BB = biceps brachii; MVC-BBt = test of maximum voluntary contraction for BB; MVC-fore = test of maximum voluntary contraction for forearm muscles; MVC-TBt = test of maximum voluntary contraction for TB; TB = triceps brachii.

the results of a *post-hoc* analysis when different measures of one muscle were compared.

4. Discussion

The results of this study did not show any differences between the first and second measurements of maximum capabilities and the corresponding measures of EMG signal. The lack of significant differences in maximum force and in both time and frequency domain EMG measures indicates reliability and lack of fatigue caused by exerting MVC [3,4].

The values of the amplitude and spectral measures for BB and TB were different in the three tests (when acting as agonistics, antagonistics or stabilizers). In BB, the spectral measures during the agonistic test were the same as during the test for forearm muscles (except for Pf), but during the antagonistic test the values of nMF, nMPF and nPf were lower. In TB, all spectral measures during the antagonistic test were lower than in the agonistic test. When the agonistic test was compared with the test for forearm muscles, the spectral measures were significantly higher, with the amplitude significantly lower. When comparing EMG measures in both BB and TB, the increase in nRMS was in step with the increase in spectral measures (nBf for BB was an exception). Those differences can be related to the dependence of the amplitude and frequency measures on muscle contraction level.

However, the results of the MVC tests activating BB and TB showed obvious differences in EMG measures, which most probably resulted from differences in muscle contraction level. The results on the often studied relationship between muscle force and surface EMG measures describing the power spectrum are contradictory, however. Numerous researchers reported growth in spectral EMG measures with muscle force [12,13]. Other researchers reported hardly any change [14]. Still others reported a decrease in parameters in some cases [15].

The amount of force produced by a muscle depends on the motor unit activation patterns and the mechanical properties of muscle fibres. nRMS, which represents the muscle contraction level, was below 10% MVC for BB in MVC-TBt and TB in MVC-BBt; there were no significant differences. However, the differences between the results obtained for those two muscles during the two tests consisted of spectral measures. That indicates that the differences between BB and TB in spectral measures can be associated with the type of external exerted force (pulling or pushing). BB was an agonist that produced flexion at the elbow, which means it contracted during pulling. TB extends the elbow, which means it was activated during pushing.

The antagonist muscles (BB in pushing and TB in pulling) were characterized by a muscle contraction level close to the level obtained during relaxation (no statistically significant differences in nRMS). However, there were differences when frequency measures were considered. When force exertion tests (muscles acting as antagonists) were considered, with small values of amplitude also the frequency domain measures were lower than 1. Spectral measures (nMPF, nMF, nBf) in relaxation exceeded 1 with more than twofold differences. This confirms earlier results showing a rapid increase in MF and MPF when muscles contracted at a very low level or when they were relaxed [2].

A comparison of MVC-BBt with MVC-fore for TB and MVC-TBt with MVC-fore for BB indicated differences in amplitude and frequency measures, which could have resulted from the elbow angle (muscle length). Some studies reported that an increase in muscle length caused a decrease in the amplitude of the EMG signal [16]. However, others reported a decrease in muscle length resulting in a decrease in EMG amplitude [17]. Roman-Liu and Bartuzi [18] showed that a decrease in muscle length caused by altering the wrist posture influenced the relationship between the time and frequency measures in forearm muscles, whereas an increase in muscle length did not. Studies on BB [19,20] and TB [20] showed an increase in spectral parameters such as MF and MPF when the length of muscle decreased. The trend of an increase in the values of spectral parameters (MPF and MF) during muscle shortening may be consistent with the results obtained for BB in the present study.

The proportion of type I (slow) and type II (fast) muscle fibres has a significant impact on the difference in the amplitude of surface EMG and the power of the spectrum characterized by the value of MPF and MF [21]. Johnson et al. [22] indicated that the percentage of

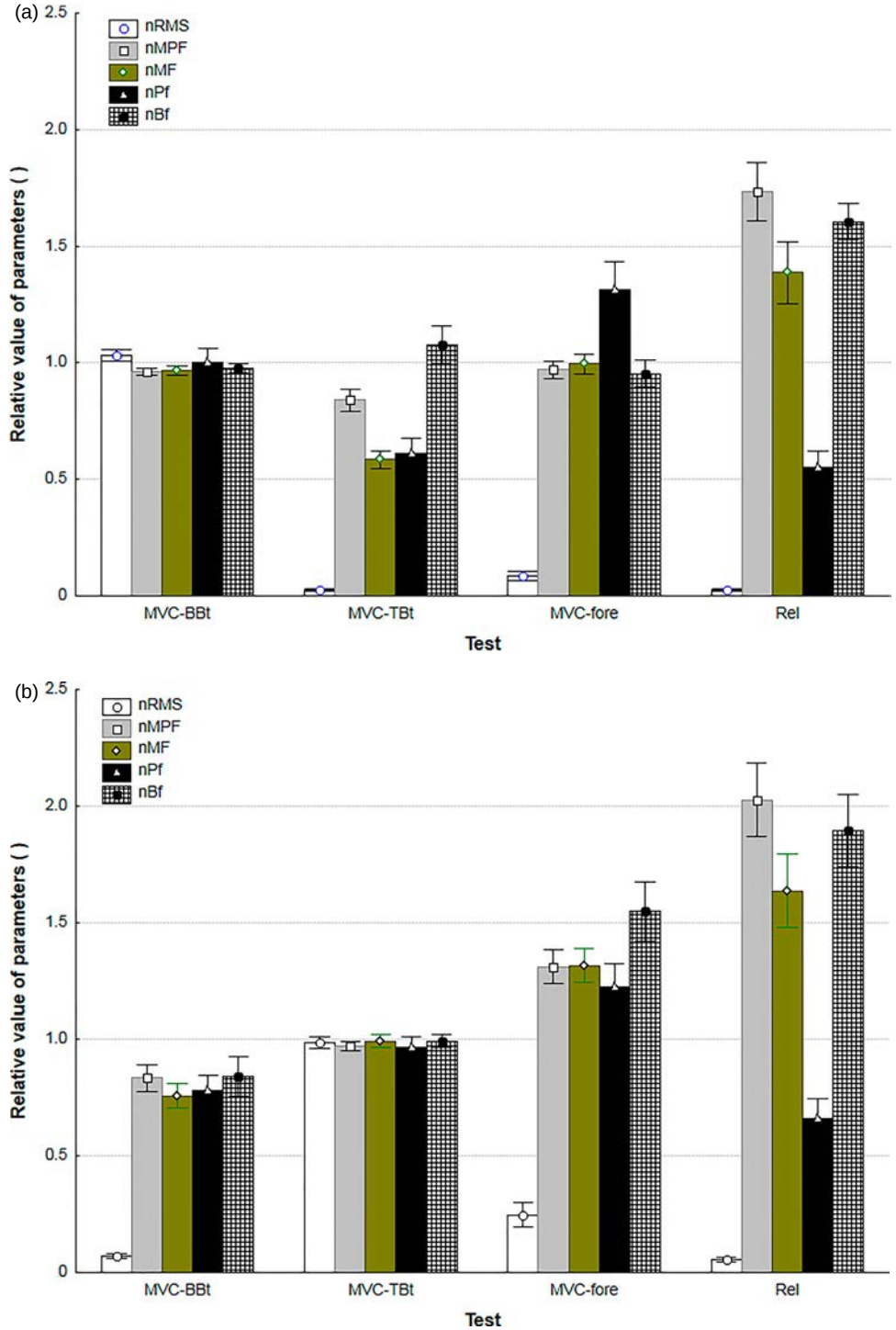

Figure 2. Mean values and standard error (error bars) of normalized electromyography measures obtained from: (a) biceps brachii; (b) triceps brachii.

Note: MVC-BBt = test of maximum voluntary contraction for biceps brachii (BB); MVC-fore = test of maximum voluntary contraction for forearm muscles; MVC-TBt = test of maximum voluntary contraction for triceps brachii (TB); nBf = normalized border frequency of the spectrum (the highest frequency of power representing the sample for which the normalized value equals 0.01); nMF = normalized median frequency; nMPF = normalized mean power frequency; nPf = normalized peak frequency of the spectrum; nRMS = normalized amplitude of root mean square; Rel = relaxation in the same upper limb posture as during MVC-BBt and MVC-TBt.

Table 2. Results of *post-hoc* Friedman analysis of variance (difference between averaged rank) indicating differences in electromyography measures between tests comparing measures inside for each muscle.

	BB					TB				
Compared cases	nRMS	nMPF	nMF	nPf	nBf	nRMS	nMPF	nMF	nPf	nBf
MVC-TBt vs. MVC-BBt	1.94	0.59	1.67	1.30	0.92	1.91	0.52	0.84	0.65	0.58
MVC-fore vs. MVC-BBt	1.13	**0.06**	**0.03**	0.61	**0.38**	0.74	1.71	1.83	1.04	1.67
MVC-fore vs. MVC-TBt	0.81	0.53	0.53	1.72	0.82	1.17	1.19	1.00	0.54	1.08
Rel vs. MVC-TBt	**0.50**	2.12	2.12	**0.29**	2.65	2.79	1.86	1.13	1.14	1.77
Rel vs. MVC-BBt	2.98	1.53	1.53	1.59	1.45	**0.49**	2.39	1.97	**0.44**	2.35
Rel vs. MVC-fore	1,79	1.59	1.59	2.00	1.83	1.62	0.68	0.58	1.68	0.68

Note: Cases with no statistical significance are indicated in bold. BB = biceps brachii; MVC-BBt = test generating maximum voluntary contraction of BB; MVC-fore = test of maximum voluntary contraction for forearm muscles; MVC-TBt = test generating maximum voluntary contraction of TB; nBf = normalized border frequency of the spectrum (the highest frequency of power representing the sample for which the normalized value equals 0.01); nMF = normalized median frequency; nMPF = normalized mean power frequency; nPf = normalized peak frequency of the spectrum; nRMS = normalized amplitude of root mean square; Rel = relaxation in the same upper limb posture as during MVC-BBt and MVC-TBt; TB = triceps brachii.

type I fibres in BB ranged from 42.3% near the surface to 50.5% deeper under the skin. Barter et al. [23] and Miller et al. [24] obtained similar results in TB: 32.5 and 32.7%, respectively. However, according to Schantz et al. [25], it was 50% in TB. This suggests that although there are individual differences, the differences in EMG variables probably also result from the different muscle structure in BB and TB.

The EMG signal is usually characterized with MF and MPF. The present study also analysed Bf and Pf. The results showed that Pf was less sensitive to muscle force. However, it changes due to muscle length determined by elbow angle. Bf changes are more in step with changes in MF and MPF. Kaplanis et al. [26] explored the various parameters which characterized the power spectrum like MF, Pf, peak value and power spectrum capacity. Their research showed a slight decrease in the value of MF with muscle force in the range 10−100% MVC. However, there were no changes in the frequency values corresponding to the peak of the spectrum. The present study showed sensitivity of Pf to different MVC tests. Parameters of the time domain are common and easier to interpret. Therefore, they are often used for various purposes. Spectral parameters play an important role; however, it is more difficult to interpret the influence of intrinsic and extrinsic factors on those parameters. Because of the influence of individual factors on EMG spectral measures, an analysis of the EMG signal may also require spectral parameters. That may indicate the need for a more profound analysis of spectral measures other than MF and MPF.

The main limitation of the study is that the different positions of the elbow can cause displacement of the electrodes in relation to the position of the examined muscle, which may also influence the EMG signal and, thus, the measures [27,28]. This cannot be controlled in surface EMG, and therefore it cannot be unambiguously stated whether the results have or have not been influenced by changes in muscle length or electrode displacement. The other limitation is related to possible crosstalk. To reduce the risk of crosstalk, the EMG signal was recorded with double-differential electrodes [27].

5. Conclusion

The study showed no differences in amplitude between relaxation and MVC antagonist in static contraction, with higher values for frequency measures in relaxation. When BB and TB act as antagonists in an MVC test, frequency measures present lower values than when the muscles act as agonists. When acting as stabilizers during handgrip force, BB and TB differ. BB shows much lower amplitude than during agonist MVC contraction with similar spectral measures. TB presents much higher values of spectral measures than during an agonist MVC test.

To sum up, the results of the present study showed that the type of exerted force, i.e., if BB and TB acted as agonists, antagonists or stabilizers, affected the relationship between the time and frequency domain measures. This observation can be useful in analysing spectral measures for different muscle contraction levels when a muscle acts differently during normalization than during the proper test.

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