THE IMPORTANCE OF ELECTROMYOGRAPHY AND CONTRACTION MECHANOGRAM IN THE STUDY OF MUSCULAR FATIGUE

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ABSTRACT

Introduction: A controversial topic in physiology is muscular fatigue, raising still unanswered questions regarding its causes and mechanisms.
Aims: To investigate the role of electromyography and contraction mechanogram in the evaluation of muscular fatigue and to establish the circumstances that ensures a greater physical effort with a lesser degree of muscular fatigue.
Materials: Ten healthy subjects in whom we recorded the global surface electromyogram (SEMG) and muscular contraction mechanogram using a Medicore (type MG 42) electromyograph (produced in Hungary), respectively a BIOPAC system (USA). Muscular recordings were stored and subsequently processed using two personal computers.
Methods: The study was performed on ten healthy subjects, of both genders and similar ages, and consisted in the recording of global surface electromyography (SEMG) and mechanogram of the voluntary maximal isometric contractions of the finger flexor in two different sessions of physical effort:
-voluntary maximal isometric contractions of short duration (high frequency - Hi) - 4 sec, followed by rest intervals of 6 sec - 30 contractions in 5 min;
-voluntary maximal isometric contractions of longer duration (low frequency - Lo) - 40 sec, with rest intervals of 60 sec - total 3 contractions in 5 minutes.
In both cases, during the 5-minute sessions, the subjects contracted the finger flexor for 120 sec, while the total rest period was 180 seconds.
Results: The results are synthetically represented in several tables.
Conclusions: When the muscular contractions and the resting intervals are shorter, the total global physical effort performed in the same unit of time is 32% greater and with less fatigue, than when muscular contractions and resting intervals are longer.

Key words: electromyogram, contraction mechanogram, muscular fatigue

INTRODUCTION AND AIMS

A debated issue in physiology is muscular fatigue which still has many unanswered questions relative to its causes and mechanisms of development.

In a previous study,[1] subjects performed a constant muscular effort of 20 Kpm per second on a cycloergometer. The ratio between contraction and rest periods was constant (2/3). Three cycles of muscular contractions with different total time for each of them were studied. It was concluded that the shorter was the muscular contractions and the rest intervals between them, the development of muscular fatigue was delayed and the total muscular work was greater.

Muscular fatigue occurs at a certain threshold, called of resistance to prolonged effort.[1,2] The value of this threshold, equivalent to the amount of physical effort made in order to reach a state of muscular fatigue, is a variable factor which depends on: health state (healthy vs. unhealthy person), gender, age, level of physical conditioning (trained vs. untrained), the hour at which the physical effort is performed (midnight is the least effective period), the ratio between contraction and resting period and the characteristics of muscles involved in the physical effort.

The main aim of this study is to verify what kind of physical effort is the best choice for healthy non-trained persons to achieve a sportive performance and a rapid development of muscular mass with less muscular fatigue during a two cycles of muscular activity. The second aim was to examine what correlations can be made between the duration of muscular contractions and muscular fatigue and to measure what type of contractions lead to a higher muscular work in the same unit of time.

We performed a experiment according to the protocols already described,[1-5] with the following

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modifications: a force transductor of a BIOPAC system was used instead of a cycloergometer; several electromyographical parameters were recorded during exercise; the subjects performed a maximum voluntary muscular contraction with a variable intensity from one individual to another and from one recording to another (rather than a constant muscular contraction described in the previous studies), isometric (rather than the isotonic type of contraction on cycloergometer) of the flexor shared by the right-hand fingers.

MATERIALS AND METHOD

The study group

The study was performed on ten healthy subjects, of both genders and similar ages, whose characteristics are presented in Table 1.

The equipment used for the digital recording and processing of the global Surface Electromyogram (SEMG) and mechanogram

-Electrodes: Medicore, formed of chloride silver plates with the surface area of 0.8 cm^2.

-Electromyograph Medicore type MG 42 (Hungary) - for SEMG recordings

-The acquisition and digital processing of the electromyograghic signal – DAP 1200 plate introduced into an IBM PC AT 486 (66 MHz).

-Force isometric transducer coupled to an acquisition unit MP30 of the BIOPAC System (SUA) for the recording of the contraction mechanogram

-Wilcoxon soft ware was used for statistical data processing.

METHOD

Global surface electromyography (SEMG) and mechanogram of the voluntary maximal isometric contraction of the finger flexor (*flexor digitorum superficialis* and *flexor digitorum profundus*) were performed in two different sessions of physical effort:

-voluntary maximal isometric contractions of short duration (high frequency – Hi) – 4 seconds, followed by rest intervals of 6 seconds; 30 contractions in 5 minutes;

-voluntary maximal isometric contractions of longer duration (low frequency – Lo) – 40 seconds, with rest intervals of 60 seconds; total 3 contractions in 5 minutes.

In both cases, during the 5 minute-long exercise, the subject contracted the finger flexor for 120 seconds, with a total resting period of 180 seconds.

On the completion of the exercise, two recordings have been performed (EMG and mechanogram) for each subject, one at high frequency, then, after an hour of rest, at low frequency.

The SEMG was recorded during a 410 ms period only at the end of the contraction (3 acquisitions within 5 minutes for the low-frequency contractions, and 30 acquisitions within 5 minutes for the high-frequency contractions). Mechanogram was recorded over the whole duration of a muscular contraction.

Electromyographical parameters recorded:

Time parameters:

1. Maximum amplitude (Amax)(mV);
2. Average rectified value of the signal (Var)(mV);
3. Average square value of the signal (Vas)(mV);
4. Number of return points (Nrp)(Hz);
5. Number of crossing through zero (Ncz)(Hz);
6. Integral of the rectified signal (Irs)(mVms);
7. Ratio average area/ average amplitude (Raa)(ms);

Frequency parameters:

1. Synchronization
2. Average frequency (Fav)(Hz);
3. Median frequency (Fmed)(Hz);
4. Maximum strength density (Smax)(mV^2/ms);
5. Frequency at which the maximum strength density appears (Fsmax)(Hz).

Myographic parameter:

1. Area of kinetic activity (Kgf.s)

Stages of experiment:

1. Complete explanation on the experiment and recording of the informed consent
2. Calibration of equipment
3. Exercise completion, digital recording and processing of obtained data

Table 1. Characteristics of the study group

	No	Average Age	Stand.dev.	CV%	Min. Value	Max. Value	P
Men	6	48.33333	16.57408	34.17335	35	76	0.144858
Women	4	36.5	4.932883	13.51475	31	42	
Total	10	43.7	14.11107	32.29077	31	76	

RESULTS

The initial values of all parameters (SEMG and mechanographic parameters) during both cycles (high and low frequency muscular contractions), for all the subjects under observation, together with the data resulted from the statistical processing are presented in tables 2 and 3.

The differences between the first and last mean values of the studied electromyograhic parameters, expressed as percentage of the initial mean value, for the two types of contraction, are shown in the table 4.

In order to get the same intensity of muscular work in both cycles of muscular contractions, we reduced the differences between the first and last mean value of all electromyograhic parameters during high frequency contractions by 32.91% (the percentage difference of myographical parameter "Total area of kinetic activity" in the situation of two cycles-Hi and Lo); results are depicted in table 5.

Figure 1 presents the absolute values of the total area of kinetic activity in the two cycles of exercise.

Table 2. Study group SEMG and mechanographic parameters for the cycle of high frequency muscular contractions (Hi) and the statistical data processing

Hi	Fmed	Fav	Smax	Fsmax	Amax	Var	Vas	Nrp	Ncz	Isr	Raa	Synchroni-zation	Area
1	105.6	124.7	81.8	81.8	2.12	0.20	2.12	195.9	129.2	82.7	2.0	17.3	1582.6
2	109.7	136.8	81.5	81.5	1.14	0.11	1.14	216.7	138.6	45.4	1.96	18.9	845.3
3	89.4	108.7	71.3	71.3	2.52	0.32	2.52	192.7	121.7	130.6	2.27	15.9	1484.9
4	89.	108.7	71.7	71.7	2.40	0.78	2.40	192.5	121.1	130.3	2.20	15.1	1334.7
5	80.4	98.7	71.8	71.8	1.80	0.16	1.80	209.3	121.1	67.5	2.35	25.6	546.
6	80.4	98.8	71.7	71.7	1.80	0.16	1.80	209.3	121.1	67.5	2.35	26.5	442
7	88.8	138.7	58.6	58.6	0.68	0.08	0.68	274.3	151.4	31.7	2.02	25.6	195.8
8	82.1	118.6	52.4	52.4	1.02	0.09	1.02	236.8	147.4	38.8	1.91	20.5	1108.1
9	114.6	143.8	82.8	82.8	2.21	0.22	2.21	152.3	117.2	91.8	2.02	19.7	2206.1
10	81.7	99.	68.2	68.3	2.98	0.40	2.98	179.	112.3	162.0	2.50	13.5	854.9
AV	92.2	117.6	71.2	71.2	1.86	0.25	1.86	205.9	128.1	84.8	2.16	19.9	1060.
STDEV	12.9	17.5	9.8	9.9	0.73	0.21	0.72	33.	13.3	43.8	0.20	4.7	607.9
CV%	14.	14.9	13.8	13.8	39.03	82.1	39.	16.1	10.3	51.6	9.31	23.4	57.3
P(t)	0.44	0.2	0.30	0.3	0.96	0.796	0.54	0.63	0.41	0.83	0.29	0.13	0.16
P(W)	0,18	0.21	0.21	0.2	0.93	0.93	0.93	0.86	0.37	0.93	0.19	0,17	0,22
Artificial percentage													100

Table 3. Study group SEMG and mechanographic parameters for the cycle of low frequency muscular contractions (Lo)-and the statistical processing.

Lo	Fmed	Fav	Smax	Fsmax	Amax	Var	Vas	Nrp	Ncz	Isr	Raa	Synchroni-zation	Area
1	95.1	109.4	92.7	92.6	1.86	0.142	0.23	193.5	115.5	57.2	2.3	26.3	1243.5
2	107.	128.3	52.6	52.6	1.67	0.148	0.24	207.8	142.6	59.5	2.24	22	566
3	90.6	106.2	98.4	98.4	3.21	0.326	0.52	164.3	109.5	131.5	2.25	15	1352.2
4	90.8	107	98.7	98.7	3.34	0.667	0.87	164.3	109.8	131.7	2.31	16	983.6
5	93.8	115.9	98.9	98.9	1.33	0.101	0.17	259.9	135	42.9	2.1	31	376.5
6	93.5	115.6	98.8	98.8	1.4	0.104	0.17	259.6	134	42.9	2.1	33	269.5
7	63.5	104.9	43.9	43.8	1.50	0.455	0.73	245	103.8	183.3	4	18	53.2
8	64.4	99.2	30.7	30.7	0.74	0.078	0.12	230.5	131.8	31.3	2.11	28.33	800.
9	96.7	111.9	111.9	111.9	1.51	0.142	0.22	183.5	124.5	57.6	2.15	24	1052.7
10	79.1	95.5	86.9	86.9	1.97	0.158	0.25	226.6	125.6	64.3	2.27	24	414.7
AV	87.4	109.4	81.3	81.3	1.85	0.23	0.35	213.5	123.23	80.2	2.38	23.7	711.2
STDEV	14.14	9.3	28.	28.1	0.81	0.192	0.26	36.4	12.98	50.3	0.57	6.1	439.9
CV%	16.16	8.5	34.5	34.5	44.12	82.8	73.8	17.1	10.5	62.7	24.17	25.8	61.8
P(t)	0.44	0.2	0.30	0.3	0.96	0.796	0.54	0.63	0.41	0.83	0.29	0.13	0.16
P(W)	0,18	0.21	0.21	0.2	0.93	0.93	0.93	0.86	0.37	0.93	0.19	0,17	0,22
Artificial percentage													-32.91%

Table 4. The differences between the first and last mean value of all electromyografic parameters, expressed as percentage of the initial mean value for the two types of contraction (Hi and Lo)

	Fmed	Fav	Smax	Fsmax	Amax	Var	Vas	Nrp	Ncz	Isr	Raa	Synchronization
Hi	-6.96%	-2.97%	0.92%	9.22%	-1.60%	-13.97%	-28.56%	-2.57%	-1.12%	-13.88%	0.04%	12.07%
Lo	-6.21%	-2.60%	-4.61%	-22.56%	-19.66%	-14.61%	-14.02%	3.14%	0.65%	-12.30%	0.79%	9.26%

Table 5. The differences between the first and last mean value of all electromyografic parameters, expressed as percentage of the initial mean value for the two types of contraction (Hi and Lo) corrected by -32,91% (for Hi)

	Fmed	Fav	Smax	Fsmax	Amax	Var	Vas	Nrp	Ncz	Isr	Raa	Synchronization
Hi	-4.67%	-1.99%	0.62%	6.19%	-1.08%	9.37%	-19.16%	-1.73%	-0.75%	-9.31%	0.02%	8.10%
Lo	-6.21%	-2.60%	-4.61%	-22.56%	-19.66%	-14.61%	-14.02%	3.14%	0.65%	-12.30%	0.79%	9.26%

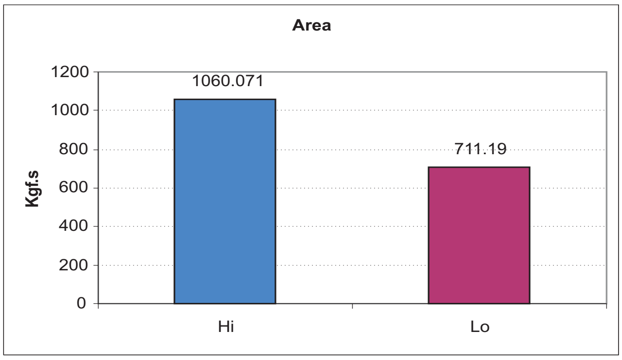

Figure1. Total area of kinetic activity during a period of 5 min. with 30 contractions - Hi or 3 contractions - Lo

DISCUSSIONS

The Romanian specialty literature on electromyography and its applications is quite reduced, currently there is available a single medical textbook[5] that presents an aplication of computerized electromyography in odontological pathology.

From 2000 to 2003 several new electromyographical parameters such as synchronisation, Fsmax and efficiency index of cuplation between electrical excitation and muscular contraction (Fmed correlated to Fsmax), as well as "area" parameter have been described.

Some authors described experiments performed on healthy subjects using a cycloergometer.[1] Muscular fatigue was detected using heart rate. Others authors have studied muscular fatigue using surface electromyography.[6-12] They studied different types of muscular effort with the concomitant recording of several electromyografic parameters such as the root mean square (Rms), average rectified (AR) value, and median frequency (MF) usually correlated to a second procedure of muscular fatigue study such as mechanomyogram (MMG). They acquired different results due to the differences between their experiments. The RMS (root mean square) of the SEMG and MMG increased with advancing fatigue; MF (median frequency) of the PSD (power density spectra) progressively decreased from the onset of the contraction.[10] In our study we observed a common behavior of several SEMG parameters (Fmed equivalent to MF, Fav equivalent to RMS) to those reported in the literature.[10]

We studied a group of 10 healthy subjects who performed two cycles of 10 muscular contractions over a period of 300 s. The ratio between men and women was 3/2 (p=0.144858). The mean age was 43.7 years.

In the first cycle of muscular effort (Hi) a contraction lasted 4 s and a rest interval was 6s. In the second cycle (Lo) the contraction time was 40 s separated by rest intervals of 60 s. The ratio between a contraction and a rest period was 2/3 in the both cycles.

Tables 2 and 3 are presented the initial values of all studied electromyographical parameters and their statistical processing data for both cycles of physical effort. Two statistical tests (Test Student (t) and Wilcoxon (W) were used for comparison of the values of the same electromyographical parameter for both types of muscular contraction (Hi and Lo).

From Table 4 one can observe that in both modalities of contractile activity, the median frequency (Fmed) practically decreases equally (by approx. 6%). The average frequency (Fav) behaves in a similar way, with a decreases of 2 to 3%. The frequency of the maximum strength density (Fsmax) modifies in the opposite directions, rising by 9.22% at Hi and decreasing by 22.56% at Lo –changes that are difficult to interpret. On the contrary, the number of return points (Nrp) decreases by 2.57% at Hi and rises by 3.14% at Lo. It is hard to understand how the Nrp should rise while the frequenciy increases. The number of crossings through zero (Ncz) behaves like Nrp (number of return points), yet with much lower percentage differences. The synchronization raises more with Hi (by 12.07%) than with Lo (9.26%).

In Table 5 all frequency parameters recorded lower variations between their initial and final mean value for Hi frequency muscular contraction cycle compared to those for Lo frequency muscular contraction cycle. Time parameters presented a similar trend to frequency parameters except for Vas and Ncz that behaved in an opposite fashion.

The behavior of almost all electromyografic parameters (except Vas and Ncz) reveals the occurrence of a greater muscular fatigue in the cycle with Lo than in the cycle with Hi.

The lower is the variation of electromyografic parameters from their initial to final value, the less is the degree of muscular fatigue.

The parameter AREA (Fig. 1) (Total Area of kinetic activity during a period of 5 minutes with 30 short contractions - Hi or with 3 prolonged contractions – Lo), is by far the most important because it indicates the original, undoubtful fact that, when we perform repeated, short maximal voluntary contractions we achieve a total contraction (equivalent to a total work effort in an isotonic contraction) 32.9% greater than (in kgfs) in the 5 minutes of prolonged and rare muscular activity.

CONCLUSIONS

1. For research on the electrical phenomena that characterize the muscular fatigue, the global surface electromyography (SEMG) is preferred due to the much simpler, more comfortable and painless technique, and more importantly to the lack of risks of haematogenous contamination with hepatic viruses, HIV or viruses still unidentified (the risk present at least theoretically in the unitary EMG recording, with Adrian-Brank needles, even disposable ones), and on the other hand to the fact that by unitary EMG kinetic unit potentials cannot be differentiated during maximal contraction (the type of contraction involved in the study of muscular fatigue).[6,7]

2. By repeated short rapid contractions the subject performs an isometric effort with 32.91% greater than by prolonged contractions (in both cases the ratio contraction/rest being equal to 2/3 and, as we have already shown, the total duration of the contraction in 5 min being in both cases equal to 120 sec).

3. The calculated SEMG and mechanographical parameters, if corrected (being brought to the situation where the effort would be identical in both cases rather than 32.91% greater in short voluntary contractions), indicate a lower level of muscular fatigue for the cycle with high frequency muscular contractions (Hi) than in the other cycle of muscular activity (Lo).

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