ORIGINAL ARTICLE

A 10-Second Measurement of Maximum Voluntary Contractions on Some Muscle Regions: A Cross-Sectional Study

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ABSTRACT

Aim: This study aims to recommend an optimal maximal voluntary isometric contraction protocol that will not cause muscle fatigue

Methods: Cross-sectional study design was conducted to measure the maximum torque values obtained during 10s self-paced gradually increasing force in 10 repetitions of maximum voluntary isometric contractions (MVICs). During the measurements, neuromuscular activity of biceps femoris (BF), gastrocnemius medialis (GM), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles were recorded.

Results: In line with the results, intraclass correlation coefficient values in the range of 0.726-0.903 were found for all variables.

Conclusion: The maximum voluntary isometric contraction protocol proposed by the research gives consistent results between measurements.

Keywords: sEMG, Maximum voluntary isometric contraction, Torque

INTRODUCTION

Electromyography is a non-invasive discipline that provides the recording of electrical signals released from active muscles by using electrodes on the skin during both dynamic (concentric, eccentric) and static (isometric) movements and deals with issues related to neuromuscular activity by analyzing these signals. Surface EMG (sEMG), a technique of electromyography, has been increasingly used in many sports branches recently.[1]

Fatigue analysis is vital in clinical research, sports biomechanics, and myoelectric control. The concept of fatigue can be evaluated in many dimensions and fatigue in sports can be evaluated in terms of nervous system fatigue, neuromuscular fatigue, and muscle fatigue. Although the term of muscle fatigue or regional muscular fatigue is generally used, fatigue can simply be determined by the amount of time an individual can sustain a particular task such as a certain isometric contraction. In this line, fatigue can be defined as a decrease in the maximal capacity to sustain a certain intensity or expected strength of any exercise. According to another definition, fatigue is related to the inability to reach the level at the beginning of a certain maximal voluntary contraction force, and the inability to maintain a mechanical performance in parallel with its intensity and duration.[2-3] Fatigue appears in the form of mechanical manifestations in the muscle at the point where the level of contraction in the muscle cannot be sustained due to physiological changes in relation to the endurance time. Physiological deterioration in the neuromuscular system caused by fatigue in sustaining muscle contraction during a muscular activity, changes in sEMG signals are myoelectric manifestations of fatigue. In this way, fatigue can be determined by analyzing sEMG signals.[2-4-5]

Using the sEMG method, fatigue of this regional muscle group can be observed by measuring the myoelectric activity of the active muscle group during an athletic performance at a certain workload.[6] sEMG is used extensively to determine regional muscle fatigue.[7] The fact that the myoelectric signals obtained from dynamic contractions are not stationary and have multicomponent can complicate the mathematical analysis process and cause difficulties. However, although isometric contractions cannot fully represent the development of muscle activity and fatigue during human movement in some cases, isometric muscle movements (actions) are very important in daily activities such as standing and carrying, and in many sports such as wrestling, gymnastics, speed skating or skiing.[2-3-8] The sEMG method, which is considered a reliable and valid method for determining electrophysiological changes during muscle fatigue, is widely used in previous studies. However, in most studies on neuromuscular activity and fatigue, fatigue is evaluated through isometric contractions.[4-9]

Regardless of the type of muscle contraction (concentric, eccentric, isometric), the prolongation of the contraction time causes the onset of muscle fatigue, which is defined as the inability to maintain force formation. The sEMG showed that the symptoms of muscle fatigue may occur before the onset of fatigue, suggesting that the susceptibility of muscles to fatigue can be evaluated non-invasively through the skin.[9] Progressive increase in fatigue reduces the neuromuscular system's capacity to produce the same level of force and ultimately causes the muscles to be unable to perform this task any longer. In order to obtain more effective results according to the necessity of isometric training or rehabilitation applications, the fatigue time in isometric exercises should be optimized.[10]

The application of maximal voluntary isometric contraction (MVIC) tests is considered to cause negative effects on results with the effects of endurance and fatigue, and lead to inconsistencies in research findings.[11] Although different contraction times varying between 2-10 seconds are applied in MVIC tests conducted in studies, it has been stated that maximum values are reached in the first 3-5 seconds and these values can be maintained for a certain period of time.[11-12] However, myoelectric manifestations become more pronounced in parallel with the further prolongation of these periods.[3]

It is difficult to establish a consensus due to differences in MVIC tests in sports sciences. Therefore, this research aims to propose an optimal method of maximal voluntary isometric contraction test protocols that would not cause muscular fatigue during isometric contractions of different durations with the sEMG method. We hypothesis that during 10 repetitive maximum voluntary isometric contractions lasting 10s, self-paced gradually increasing force application can give applicable and consistent results during maximum voluntary isometric contractions.

MATERIALS & METHODS

Research permission was obtained from the local ethical committee and written informed consent form approval was obtained from the volunteer participants (80558721/307).

This study employed an experimental research design to measure the maximum torque values obtained during 10s self-paced gradually increasing force in 10 repetitions of maximum voluntary isometric contractions (MVICs), in which repetition and at what second, and to measure the superficial EMG variables exhibited in that unit of second. During the measurements, neuromuscular activity of biceps femoris (BF), gastrocnemius medialis (GM), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles were recorded. The research consists of two intervention sessions. During the first session (Tuesday), measurements were taken from the rectus femoris, vastus lateralis, vastus medialis, and gastrocnemius muscles. In the second session (Friday), measurements were obtained from the biceps femoris muscle.

Before the measurements, a) participants applied a 15-minute standard warm-up protocol and b) ideal ergonomic settings of the isokinetic dynamometer were prepared for each volunteer participant before the MVICs measurements. After the warm-up session, the actual measurements started. After each repeat of MVICs, a break for 180s was given.

11 male volunteers (body length: 191.12±14.03cm; body weight: 83.40±8.33kg; age: 24.61±4.66 years; training age: 7.57±2.33 years) participated in the study. Since the dominant legs of all volunteer participants were right legs, all measurements were taken on the right leg.

In addition, none of the volunteer participants were disabled or received rehabilitation at the time of the measurements, and none of them reported previous lower extremity injuries.

EMG activities of the five muscles were recorded using 16-channel wireless surface electrodes (Delsys Trigno, USA). The passband, sampling rate, maximum inter-electrode impedance, and CMMR of the EMG amplifier were 20-450 Hz, 2000 Hz, 6 kΩ and 95 dB, respectively. In order to prepare the area where the EMG would be placed, the hair in the target area was shaved, dead skin was removed, the area was carefully cleaned with an alcohol swab, and the target area was lightly abraded to allow the skin electrode impedance (below 10 kΩ) to make it suitable for EMG electrode placement. The center-to-center distance between the two electrodes was taken as 1 cm.[13] For electrode placements SENIAM recommendations were applied.[14] For RF, the sensor was placed on the superior part of the patella 50% to the superior iliaca anterior spina line. Fort the VL sensor was placed 2/3 of the way on a line from the anterior spina iliaca superior to the lateral side of the patella. For the VM, the sensor was placed 80% of the way on a line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament. In the case of the BF, the sensor was placed midway on a line between the ischial tuberosity and the lateral epicondyle of the tibia. For the GM the sensor was placed on the most prominent bulge of the muscle.[14]

All EMG data were recorded during MIVCs. During MIVCs testing, the Cybex isokinetic dynamometer was attached to all volunteer participants. MVICs measurements of RF, VL, and VM muscles were performed with knee extension 65º (full extension 0º), hamstring muscle (long head of BF muscle) MVICs measurement at knee 30º in prone position and MVICs measurement of GM muscle in prone position with ankle at 15 degrees plantar flexion. After the trial measurements, 10 repetitive measurements were performed for 10s. After each repetition, a 180s rest was given. In order to maximize performance during the test, standardized verbal motivation was applied to all volunteer participants.[15]

All maximum EMG signals recorded during maximum voluntary isometric contractions were processed using Matlab (MathWorks R2018a). The EMG signals were band-pass filtered (20–450 Hz, 6th-order Butterworth) for fatigue analysis and additionally smoothed using an rms-filter with 100 ms time-window for amplitude analysis.[13]

RESULTS

Table 1 shows that all volunteer participants reached the maximal mV, Hz, peak torque and maximal times of BF, GM, RF, VL and VM muscles and the number of repetitions they reached to the maximal.

Table 1. Maximal values of all variables for each participant

Muscle Regions & Variabes	Participants										
Biceps Femoris	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
EMG (mV)	3.29	2.04	3.84	1.44	0.71	1.21	1.95	3.34	1.34	2.12	1.46
Mean Frequency (MNF – Hz)	103.06	89.23	71.46	94.12	111.13	67.69	89.54	67.08	100.9	91.53	90.56
Peak Torque (Nm)	66.99	94.11	67.26	84.61	66.17	99.94	149.97	90.58	91.78	98.9	97
Time to Maximal	4.85	8.30	9.46	7.98	7.88	7.15	7.2	7.65	7.58	6.48	7.83
Number of Repetitions Reached to the Maximal	7	5	7	6	5	6	9	9	8	4	4
Rectus Femoris	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
EMG (mV)	3.40	1.16	1.83	2.63	2.96	1.21	1.19	2.50	2.28	2.40	0.50
Mean Frequency (MNF – Hz)	135.3	128.05	81.98	84.53	130.06	66	81.79	77.17	72.45	107.42	94.26
Peak Torque (Nm)	260.22	259.95	359.88	433.65	309.17	399.98	395.95	412.36	490.60	375.61	368.02
Time to Maximal	6.93	8.02	7.29	6.89	6.20	7.46	7.48	7.20	6.79	6.76	6.83
Number of Repetitions Reached to the Maximal	4	8	10	6	7	8	8	10	6	5	8
Vastus Lateralis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
EMG (mV)	4.37	2.64	1.63	2.88	3.02	1.44	2.17	2.80	3.10	2.36	1.15
Mean Frequency (MNF – Hz)	117.18	93.12	57.10	82.15	133.63	73.84	121.24	97.87	100.97	83.10	64.77
Peak Torque (Nm)	260.22	259.95	359.88	433.65	309.17	399.98	395.95	412.36	490.60	375.61	368.02
Time to Maximal	7.37	4.39	6.91	6.79	6.93	6.38	7.83	7.87	6.48	6.97	6.82
Number of Repetitions Reached to the Maximal	6	5	5	6	6	6	5	5	5	5	8
Vastus Medialis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
EMG (mV)	1.55	0.95	1	1.88	3	0.58	1.54	1.92	1.74	2.16	1.14
Mean Frequency (MNF – Hz)	103.77	88.92	65.04	80.89	95.59	73.93	118.37	103.74	85.15	80.59	100.43
Peak Torque (Nm)	260.22	259.95	359.88	433.65	309.17	399.98	395.95	412.36	490.60	375.61	368.02
Time to Maximal	5.45	6.10	6.15	7.22	7.56	6.59	7.57	7.41	6.84	6.61	7.85
Number of Repetitions Reached to the Maximal	5	7	6	6	10	5	4	5	4	6	4
Gastrocnemius Medialis	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
EMG (mV)	1.65	1.76	1.03	1.54	2.20	1.16	0.85	0.86	1.1	1.06	0.80
Mean Frequency (MNF – Hz)	103.06	89.23	71.46	94.12	111.13	67.69	89.54	67.08	100.90	91.53	90.56
Peak Torque (Nm)	81.36	87.19	93.56	104.85	74.58	66.04	108.75	82.89	94.32	78.78	78.38
Time to Maximal	5.77	6.58	7.64	7.36	7.29	7.13	7.90	7.22	6.63	6.87	6.72
Number of Repetitions Reached to the Maximal	7	6	3	6	3	9	4	6	6	3	7

Table 2. Intraclass Correlation Coefficients (ICC) For All Variables

Muscle Regions	Time to Maximal	Number of Repetitions Reached to the Maximal	EMG (mV)	Mean Frequency (MNF – Hz)	Peak Torque (Nm)
Biceps Femoris	0,726	0,811	0,866	0,804	0,752
Rectus Femoris	0,838	0,864	0,813	0,786	0,831
Vastus Lateralis	0,881	0,863	0,822	0,766	0,806
Vastus Medialis	0,886	0,891	0,874	0,854	0,903
Gastrocnemius Medialis	0,721	0,747	0,814	0,783	0,845

In Table 2, the intraclass correlation coefficients (ICC) values of all variables are given. According to Sleivert and Wenger[16] if the ICC is in the range of 0.800-1,000, a good repeatability level, a medium repeatability level in the range of 0.600-0.790, and a low repeatability level if it is less than 0.600. When the results are examined, it is seen that all variables are in the range of medium repeatability level and good repeatability level (>0.600). Time to reach maximal for biceps femoris and gastrocnemius medialis (ICC: 0.726, 0.721 respectively), number of repetitions reached to the maximal (ICC: 0.747), for gastrocnemius medialis, mean frequency for rectus femoris and vastus lateralis (ICC: 0.786, 0.766, respectively) and for biceps femoris (ICC: 0.752), moderate reproducibility levels were obtained at peak torque values. For all other variables, the ICC is at a good level of repeatability (>0.800).

DISCUSSION

This research aims to examine whether the applied MVIC protocol creates as much fatigue as possible during maximum voluntary isometric contractions. Therefore, the maximal testing process was divided into two days and rested for 180 s between each repetition. However, as is known, very different fatigue patterns can be observed. For example, someone with a high rate of slow-twitch muscle fibers has a much higher resistance to fatigue.[17] Table 2 shows that the ICC values of the repetitions are higher than 0.800, except for the gastrocnemius medialis. These results indicate that there are consistent peak torque values between repetitions without the effect of fatigue.

When the maximum EMG values are examined, ICC values are at a good reproducibility level for the target muscles. While there is an increase in EMG RMS values with fatigue, a decrease in maximum exhibited torque values can be observed.[18] The absence of statistically significant results in the ICC values of both mV and MNF-Hz variables can be explained by the fact that the fatigue effect was not revealed during the tests.

In their study, Shwartz et al[19] tried to create an optimal test protocol by making a minimum number of maximal voluntary contractions for the shoulder region. Since the shoulder region consists of more than one muscle, more than one maximal voluntary contraction tests are performed in this region. In the proposed protocol, it consists of 3 repetitive maximal voluntary contractions lasting 5s, and they recommend resting in the range of 30 - 180 seconds to prevent fatigue. Bussey et al[20] used a 3-second single repetition MVIC in their study. Giske et al.[21] used a 6-second three repetitions MVIC in their study. Norcoss et al.[22] obtained %MVIC data with 3 repetitions of 5 seconds MVIC. As can be seen in the relevant literature, different protocols are applied during repetition and maximum voluntary isometric contractions. During these protocols, no force was applied gradually. Soylu and Avsar[23], on the other hand, stated in their study that the application of gradually increasing force, which lasts for 10 seconds, during MVIC, which lasts for 2 seconds, would be safer than sudden contractions and it is a safer application against possible musculoskeletal system injuries. In our study, unlike this situation, the time was left to individuals without putting a limit on the application of gradually increasing force. During sEMG recordings of MVC studies, contraction of the muscles should occur gradually, not abruptly, as the principle of isometric contraction may be violated at the onset of contraction. Thus, overloading can be prevented.[23-24]

Since EMG is an important parameter especially in the clinical field and MVIC used in the normalization of this important parameter is the golden standard, the test protocols used should also be reliable.[25] Although the protocol used gives consistent results, validity-reliability applications should be added to future studies.

CONCLUSION

The study proposes an alternative and consistent protocol to the different MVIC protocols in the literature without creating fatigue. According to the ICC results of 10 repetitions of gradually increasing force MVIC application lasting 10s, each repetition gives consistent results without creating fatigue.

Recommendations: Future research can compare the same protocol with different protocols. In addition, a comprehensive validity-reliability study can be conducted in the future.

Limitations: The research protocol was applied by including restricted muscle groups. The muscles examined in the research were EMG activity and peak torque values of biceps femoris (BF), gastrocnemius medialis (GM), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles.

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