COMPARISON OF THREE EMG-BASED MUSCLE FATIGUE ASSESSMENTS IN DYNAMIC CONTRACTIONS

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The aim of this study was to (1) focus on the number of peaks methods (NoP) as an alternative method for electromyography (EMG) analysis and to (2) compare the performance of this method with two traditional EMG parameters, mean frequency (MNF) and median frequency (MDF) in assessment of muscle fatigue during cyclic dynamic contractions. A total of 6 participants performed 50 repeated, maximal concentric isokinetic muscle actions of the left leg extensors at a velocity of 180 deg/s using an isokinetic dynamometer. Quantification of the EMG activity of the muscles at each repetition was made by using three methods. NoP values were found to be positively correlated with the peak torque as well as MNF, and MDF. The study showed that the NoP method which has a simple implementation, can be used for assessing the level of muscle fatigue.

KEYWORDS: Electromyography, isokinetic, dynamic contractions, muscle force, fatigue

INTRODUCTION: Dynamic strength, endurance and fatigue of human skeletal muscle is often measured by using isokinetic dynamometers. In isokinetic testing, peak torque (PT) is one of the prominent biomechanical variables which is used to evaluate the muscle performance. Besides, the muscle activity which is observed as electromyography (EMG) generally utilized to quantify the developed force by a muscle. The most popular frequency-domain features of surface EMG are median frequency (MDF) and mean frequency (MNF) of the power spectral density which are frequently used for assessment of muscle fatigue. In the previous study (Özgören and Arıtan, 2016), number of peaks (NoP) method, was used for the quantification of EMG activity during cyclic dynamic contractions where the level of muscle fatigue was assessed based on NoP results. Similar methods were previously used (Dayan, Spulber, Eftekhar, Georgiou, Bergmann and McGregor, 2012; Gabriel, 2000; Calder, Gabriel and McLean, 2009; Gabriel, Christie, Inglis and Kamen, 2011; Gabriel, Lester, Lenhardt and Cambridge, 2007) in a number of studies where researchers focused on the change in various EMG signal spike parameters. Reliability of the NoP method was considered to be discussed by taking the results of similar frequency based analysis methods into account. From this point of view, the aim of this study was to compare the performance of NoP method with MNF and MDF in assessment of muscle fatigue from EMG signals during cyclic dynamic contractions for three leg extensor muscles, rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL).

METHODS: Five male and one female healthy volunteers (age: 25 ± 2.5 years, height: 1.79 ± 0.01 m, bodyweight: 76.8 ± 10.7 kg) participated in this study. Each participant performed 50 repeated maximal concentric isokinetic concentric knee extension of the left leg from 90° of flexion to 0° at a velocity of 180 deg/s using an isokinetic dynamometer (Cybex-Humac Norm, U.S.). EMG signals were collected from the left RF, VM, and VL muscles throughout testing with surface electrodes of a Bagnoli 8-channel desktop system (Delsys Inc., U.S.). The EMG signals were sampled with a frequency of 1 kHz and amplified with a gain of 1000. A reference electrode was placed over the right iliac crest.

EMG signal and torque data processing was then performed using custom written codes in MATLAB (MathWorks Inc., U.S.). EMG signals were digitally zero-phase filtered by a 3rd order Butterworth band-pass filter (20 to 250 Hz). The duration of each concentric knee extension was 500 ms since the velocity of the dynamometer was 180 deg/s. Thus the EMG signal groups of 50 concentric isokinetic muscle action were automatically detected after the first signal of the first group was selected. The power-density spectrum was obtained using the fast Fourier transform (FFT) technique. Then MNF and MDF of the power spectrum were computed from the EMG signal group for each concentric phase of the contraction cycle. The peaks in 50 signal groups were detected and the mean value of these peaks was calculated after full wave rectification of the EMG data. For quantification of the EMG activity, the number of peak values greater than the mean value was calculated for each signal group (Özgören and Arıtan, 2016).

MNF, MDF and NoP data for all muscles, and PT data of each subject were modelled using a single-term exponential fit ($y = a.e^{bx}$) with %95 confidence bounds and parameter b was used as fatigue index. Total of 60 fatigue indices (3 indices from three methods for a single muscle of one participant, 1 index from torque data for each participant) were obtained. The fatigue indices were statistically tested using Friedman's nonparametric test in order to compare the effect of used analysis method on the fatigue indices of the muscles. Wilcoxon signed-rank test was used for comparing the fatigue index samples in case of any possible difference. The relationship between PT and MDF, MNF and NoP of the muscles were analysed using linear regression analysis.

RESULTS: Mean MNF, MDF, and NoP for RF, VM, and VL exhibited a decreasing trend along with the PT as it is shown in Figure 1. There were positive significant correlations between PT and MNF, MDF, and NoP for the three muscles of all participants. The correlations among MNF, MDF and NoP were also positive (Table 1).

Table 1.
Correlation coefficients (R) between mean EMG variables obtained from three methods and the peak torque.

	Muscle		
Variables	**RF**	**VM**	**VL**
MNF – PT	0.9699†	0.8166†	0.9657†
MDF – PT	0.9721†	0.7915†	0.9595†
NoP – PT	0.9217†	0.9672†	0.9372†
MNF – MDF	0.9952†	0.9688†	0.9795†
MNF – NoP	0.8976†	0.8311†	0.8795†
MDF – NoP	0.9104†	0.7902†	0.8754†

Note that † indicates significant correlations.

The fatigue indices for PT, MNF, MDF, and NoP of all muscles were negative for all participants as it is clear from Figure 1b, 1d and 1f which indicated a decrease in all variables throughout testing. According to the Friedman's test results, there was no significant difference between the fatigue indices of RF, VM, and VL when a particular method was concerned (*p*-values for methods; MNF: 0.31, MDF: 0.60, NoP: 0.11). Obtained *p*-values for fatigue indices of each muscle from MNF, MDF, and NoP were 0.001, 0.002, and 0.007 respectively which demonstrated that the effect of at least one method on the fatigue indices was significant. Results of Wilcoxon test showed that this difference derived from only NoP of VM muscle.

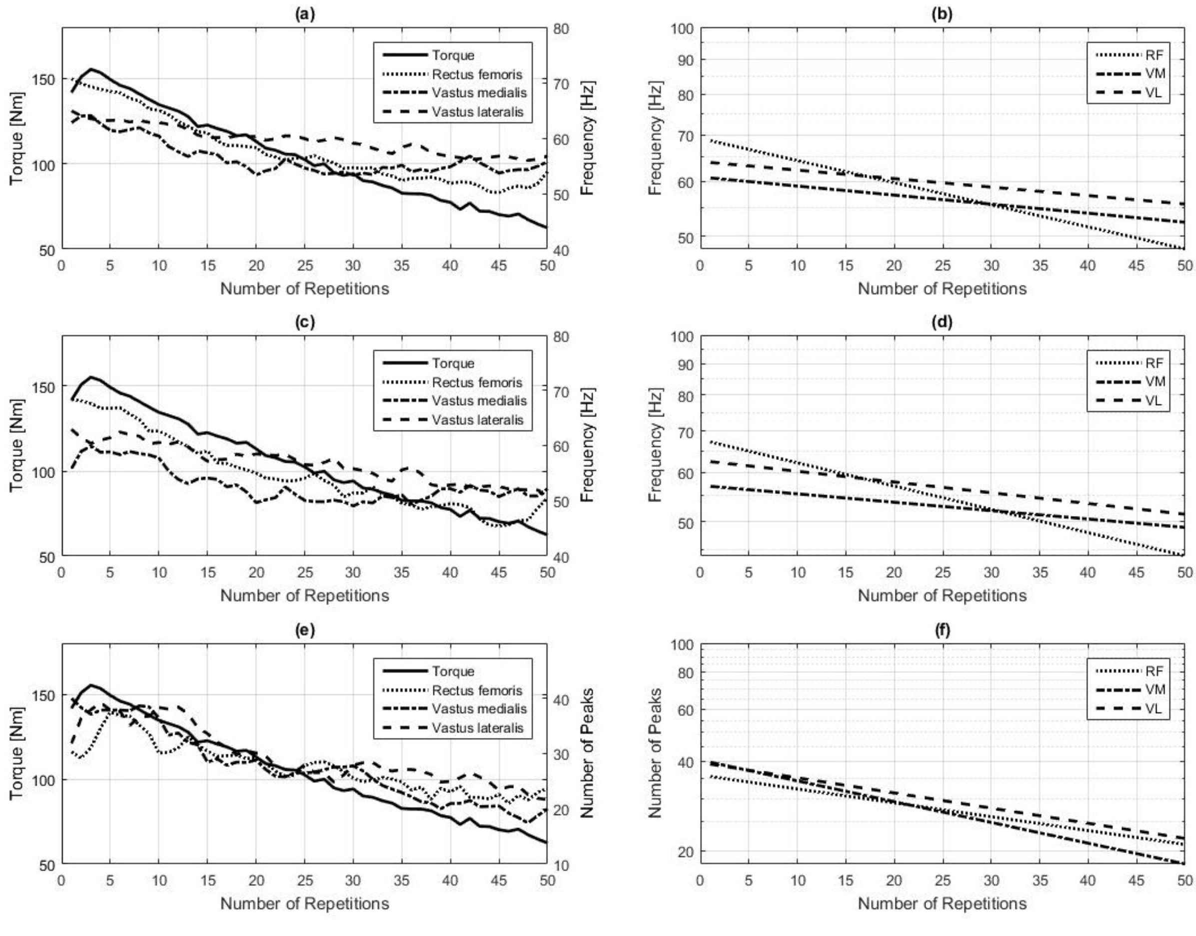

Figure 1. Change in PT and (a) MNF, (c) MDF, (e) NoP for three muscles through the test.

DISCUSSION: The data provided in Table 1 showed that NoP was positively correlated with MNF and MDF for each muscle. A significant correlation between MDF and peak counting in EMG signals for isometric contractions of RF and VL was previously shown by Dayan et al. (2012). This study demonstrated that a positive correlation exists between MDF, MNF and NoP during cyclic dynamic contractions of RF, VM, and VL. A nonlinear relationship was described between EMG and torque production using exponential functions in this study while linear (Shinohara, Kouzaki, Yoshihisa and Fukunaga, 1998) and nonlinear (Watanabe and Akima,

2006) relationships have been discussed previously. All fatigue indices were found to be negative which indicated a decline in MDF, MNF, and NoP along with the PT as it can be clearly seen in Figure 1b, 1d and 1f. When the difference in fatigue indices of VM originating from NoP method, and the stronger correlation between NoP of VM and PT (Table 1) is considered, it is suggested that NoP may be a method which is more sensitive to frequency content of the EMG signals in dynamic fatiguing exercises since VM could have a variation in fibre composition different than RF and VL. Moreover, NoP is a threshold dependent method such that the threshold is set based on the mean peak value of the complete EMG data set. So that if the VM muscle has a greater type I fibre composition, a lower peak frequency and a peak amplitude less than the threshold value is likely to be acquired in EMG signals of the VM muscle.

CONCLUSION: This study showed that NoP method can be utilized to analyse the EMG activity of RF, VM and VL muscles during dynamic concentric contractions. Further, the NoP method which has a simple implementation, can be used for assessing the level of muscle fatigue since it agrees with the traditional features, MNF, and MDF. Consequently, NoP method would rather be used for interpreting the level of muscle fatigue since MNF and MDF of the power spectral density require intensive computations.

REFERENCES

Calder, K. M., Gabriel, D. A. & McLean, L. (2009). Differences in EMG spike shape between individuals with and without non-specific arm pain. *Journal of Neuroscience Methods*. 178(1):148-156. doi: 10.1016/j.jneumeth.2008.11.015

Dayan, O., Spulber, I., Eftekhar, A., Georgiou, P., Bergmann, J. & McGregor, A. (2012). Applying EMG spike and peak counting for a real-time muscle fatigue monitoring system. In proceedings: IEEE Biomedical Circuits and Systems Conference (BioCAS), pp:41-44, 28-30 November, Hsinchu, Taiwan. doi: 10.1109/BioCAS.2012.6418474

Gabriel, D. A. (2000). Reliability of SEMG spike parameters during concentric contractions. *Electroencephalography and Clinical Neurophysiology*. 40(7): 423–430.

Gabriel, D. A., Lester, S. M., Lenhardt, S. A. & Cambridge, E. D. J. (2007). Analysis of surface EMG spike shape across different levels of isometric force. *Journal of Neuroscience Methods.* 159(1):146-152. doi:10.1016/j.jneumeth.2006.07.004

Gabriel, D. A., Christie, A., Inglis, J. G. & Kamen, G. (2011). Experimental and modelling investigation of surface EMG spike analysis. *Medical Engineering & Physics.* 33(4):427-437. doi: doi:10.1016/j.medengphy.2010.11.010

Özgören, N.Ş. & Arıtan, S. (2016). Electromyography in a 50-repetition isokinetic fatigue test. In proceedings: *14th International Sport Sciences Congress*, pp: 338, (ISBN: 978-605-83126-1-6) 1-4 November, Antalya, Turkey.

Shinohara M, Kouzaki M, Yoshihisa T, and Fukunaga T. (1998). Mechanomyogram from the different heads of the quadriceps muscle during incremental knee extension. *European Journal of Applied Physiology*, 78:289– 295.

Watanabe K. and Akima H. (2006). Normalized EMG to normalized torque relationship of vastus intermedius muscle during isometric knee extension. *European Journal of Applied Physiology,* 106:665-673.