Changes in EMG During Short Duration Supra Maximal and Long Duration Sub-maximal Exercise: A Comparative Study

Vijay Pal Singh[1], Dinesh Kant Kumar[1], Barbara Polus[2], Steve Fraser[3] and Sonia Lo Guidice[3]

[1] School of Electrical and Computer Engineering,
RMIT University, Melbourne 3000, Australia

[2] Health Sciences,
RMIT University, Bundoora 3053, Australia
[3] Medical Sciences,
RMIT University, Bundoora 3053, Australia

Abstract. Surface electromyogram (sEMG) is a non-invasive recording of the underlying muscle activities. It is used as a measure of the force of contraction, and changes in sEMG are used as an indicator for localized muscle fatigue. This paper reports a study undertaken to determine the difference in the change of sEMG due to fatigue resulting from short time sprint cycling, and long duration cycling.
This paper reports the results of the experimental study of the two kinds of exercises i.e. short duration (supra-maximal) and the long duration (sub-maximal). The results indicate that measure of the spectrum shift was effective in the detection of fatigue in supra-maximal dynamic contraction but was not useful for fatigue caused due to long duration sub-maximal cycling.

1 Introduction

The development of muscle fatigue during exercise is associated with a decrement in performance. Mechanisms of muscle fatigue depend on the exercise conditions (eg. duration and intensity) and the subject's level of physical fitness. The decrements in skeletal muscle power output is also related to neural drive reductions that may also lead to muscle fatigue in prolonged exercise [1]. This leads to the use of electromyogram - a measure of the electrical activity of the muscle - as being an indicator of muscle fatigue.

Some researchers have attempted to use the electrical activity of muscle and muscle activation using the surface electromyogram (SEMG) to study fatigue [2], [3], and [4]. SEMG is a result of summation of number of a separate motor unit action potentials in muscles and is dependent on numerous factors such as the rate of stimulation of the muscle, size of motor units recruited, morphology of the motor units, electrical properties of the tissues and the presence of any synchronization of the activity of different motor units. The rate of stimulation of the muscle and size of active motor units is dependent on the force of contraction required to be produced by the muscle. It is a complex and non-stationary signal with large inter and intra subject variations.

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Research analysis to date aimed at extracting from the SEMG an indication of localized muscle fatigue has been based on the observed shift of the power spectral density of the SEMG [5], [6]. Several other parametric measures of the SEMG signal have also been used as a relative indicator of the muscle fatigue phenomenon for an individual subject. These include the Root Mean Square (RMS), spectrum analysis (instantaneous, mean and median frequency) and zero crossing rates. When the muscle is fatigued, a strengthening of low-frequency components and a reduction in intensity of high-frequency components modifies the spectrum of the SEMG signal, measurable by parameters such as median frequency. Measure such as the wavelet coefficients provide time-frequency information and can improve the reliability of classification of sEMG [7] [8].

During cycling, there is a high degree of variation in the magnitude of sEMG in each cycle. For the purpose of comparing sEMG parameters from any two cycles, the authors have earlier demonstrated the use of short-term window at the peak activity for any cycle [9]. The inter-experiment variability of the magnitude and spectrum of sEMG is extremely large. To overcome this, the authors have proposed the normalization of the parameters by considering the ratio of the recordings taken near the fatigued and healthy state of the muscle [9]. This paper reports the comparison of the shift in the spectrum due to fatigue for long-duration and sprint cycling using the above-mentioned technique.

2 Methodology

Experiments were conducted where sEMG was recorded while the subjects did their cycling. The experiments involved sprint cycling and long duration cycling. The recorded signals were analysed to determine the spectral shift due to the onset of fatigue. The experiments are detailed below:

2.1 Subjects and Exercise

Short duration. Eleven healthy male subjects performed this exercise, but due to data corruption, SEMG of only seven subjects was analyzed. This exercise comprised of a short duration (30 second) cycling on Lode - ergometer with customized software to fatigue the subjects. Subjects were termed fatigued when the power output dropped by more than 33%.

Long duration. Nine healthy male subjects performed this exercise, but due to data corruption, SEMG of only seven subjects was analysed. Subjects did cycling exercise for as long as they could at sub - maximal level on Lode - ergometer with customised software to fatigue the subjects. Subjects were termed fatigued at the end of the exercise. Since the duration of each participant was different, hence his or her time duration were normalized for the analysis purpose.

2.2 Placement of Electrodes

Electrodes were placed at quadriceps. Electrode placement is as shown in the table 1. The skin was lightly abraded using disposable skin defoliator and cleaned with a swab soaked in alcohol to reduce skin impedance to less than 60 K. Heart-rate was monitored (Polar, Finland) to ensure safety of the participant. SEMG was recorded from the three channels (Table 1) using Delysis (USA) SEMG recording system with fixed inter-electrode distance, and proprietary electrodes.

Table 1. Channel Assignment for different muscles.

Channel 1	Vastus Lateralis (outside thigh muscle - front)
Channel 2	Vastus Lateralis (inside thigh muscle - front)
Channel 3	Rectus femoris (middle thigh muscle - front)

Analysis of the raw SEMG. After identifying envelope of the raw EMG using moving RMS, and the peak of each cycle, 100 milliseconds of SEMG immediately after the peak was selected for analysis (figure 1). The first and the last cycle of the recordings were discarded because of sudden changes taking place during these segments. RMS and the median frequency were computed from this 100-millisecond window of three cycles to find out the changes occurring in the EMG as a result of fatigue after the sprint and long duration exercise. The window of 100-millisecond was chosen because EMG can be assumed to be stationary for this small amount of time period.

An average was computed for each of the two conditions for each participant. Using this, ratio of the pre and post RMS and MF was computed for each subject and for the three channels. A ratio less than one would indicate a decrease due to fatigue. Pairwise t - test using online software by SISA was conducted to evaluate the statistical significance of the results, i.e. change in the parameters in before and after fatigue scenario.

3 Results and Observations

3.1 RMS

Figure 2 shows the ratio of the RMS of three channels in short duration exercise as depicted by table 1. Figure 3 shows the same ratio but for the long duration exercise. Ratios are taken by dividing the value of RMS near the end of the exercise (where subjects are fatigued) by the value of RMS at the start of the exercise (where subjects are not fatigued). From these figures and the t test results in the statistical analysis section, we can observe that there is no significant change in the RMS in the both

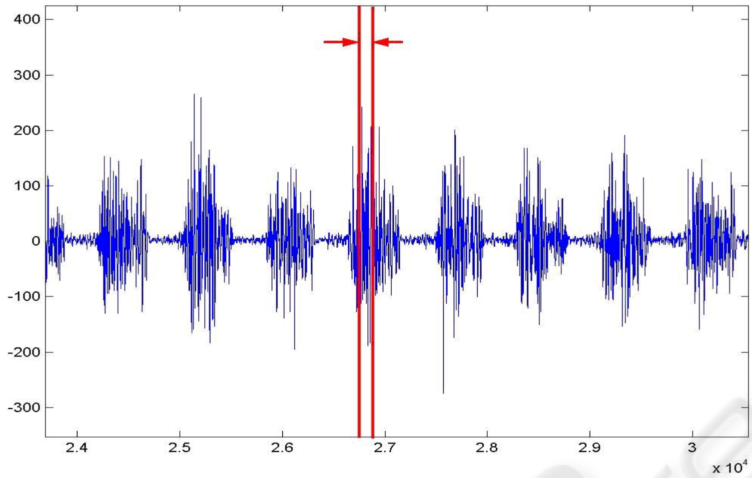

Fig. 1. Windowed Raw Signal (Illustration only) from Vastus Lateralis of one of the subjects.

cases. For short duration it can be attributed to the fact that the dynamic contraction was supra maximal right from the start and recruitment of additional motor units was not possible since increase in RMS is attributed to the increase in number of recruited motor units. There was no significant change in RMS in long duration exercise as well. Possible reason for this may be that the load on the subject was not increased during the exercise. The recruitment strategy by the peripheral nervous system may be such that in the wake of unchanged load it may be switching between different MUs to maintain a constant force until muscles ran out of energy stores.

3.2 Median Frequency

In a similar way as RMS, median frequency was calculated for the 100-millisecond window from the peak activity of each cycle. In the end the ratio of the post and pre fatigue value was taken to find out the change occurring in the median frequency. Figure 4 below shows the ratio of the median frequency in short duration while the figure 5 shows the same for the long duration exercise. Together with figure 4 and table 2 it can be very well seen that there is a significant decrease in the median frequency during the short duration supra-maximal exercise. This can be attributed to the physiological changes that happen relatively at faster rate due to subject being fatigued in only 30 seconds. As a result of this there is strengthening of lower frequency components of the surface EMG. Contrary to this there is no significant change in the median frequency in longer duration exercise as it is clear from the figure 5 and table 3.

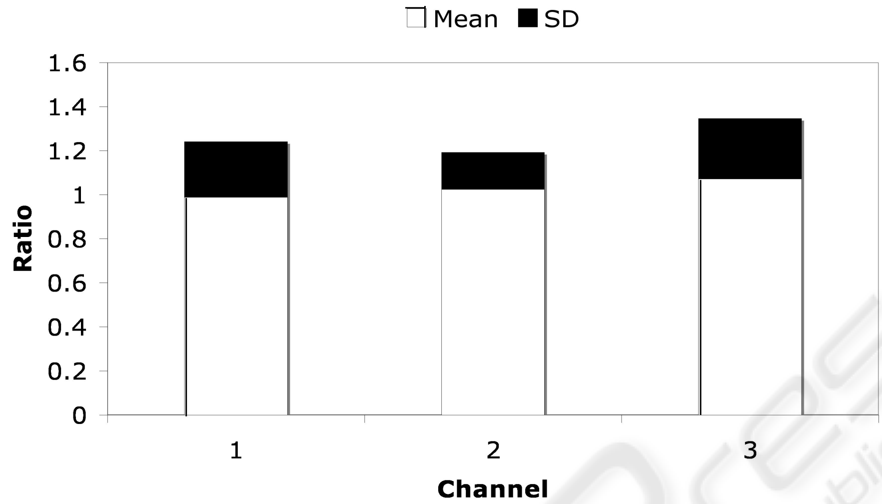

Fig. 2. Ratio of the RMS of the 100 ms window slice from the three muscles VL (1), VM (2) and RF (3) in short duration exercise.

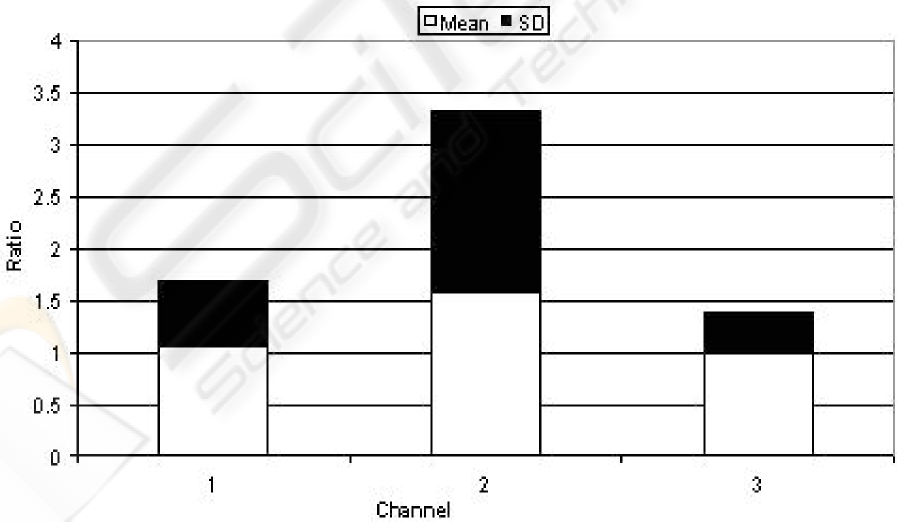

Fig. 3. Ratio of the RMS of the 100 ms window slice from the three muscles VL (1), VM (2) and RF (3) in long duration exercise.

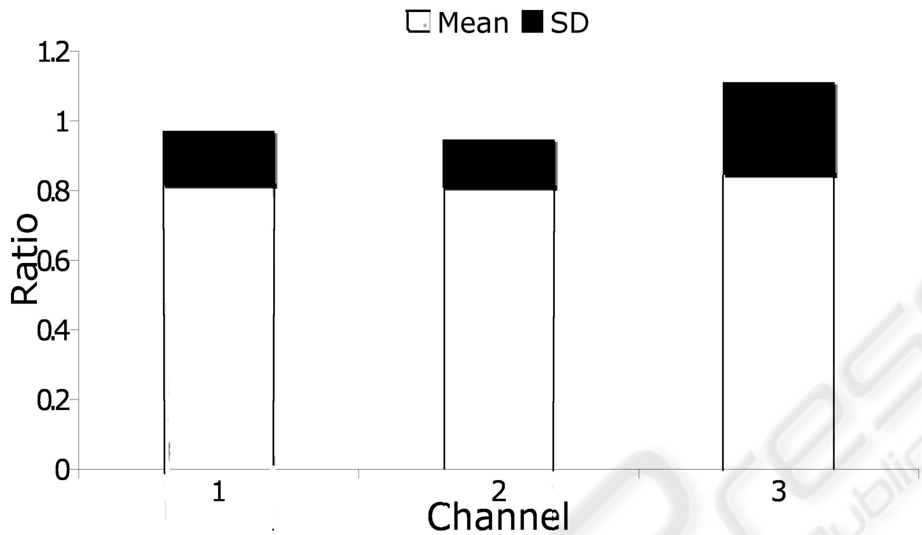

Fig. 4. Ratio of Median Frequency of the 100 ms window slice from the three muscles VL (1), VM (2) and RF (3) in the short duration exercise.

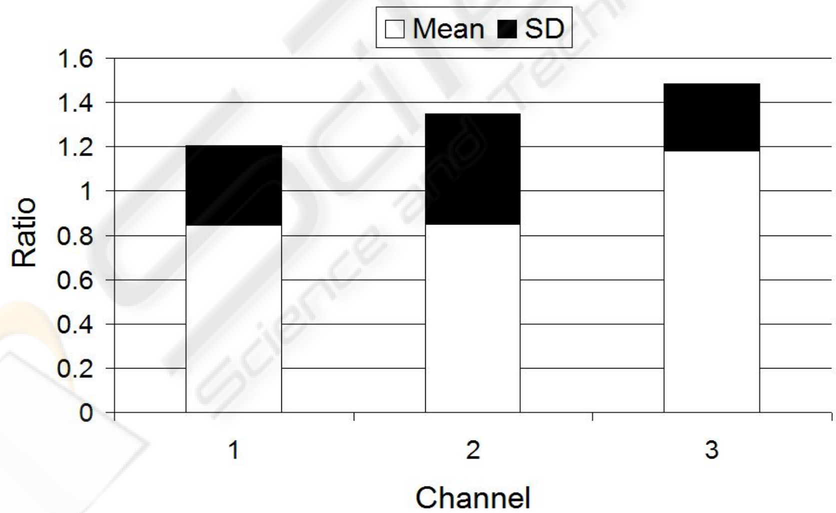

Fig. 5. Ratio of Median Frequency of the 100 ms window slice from the three muscles VL (1), VM (2) and RF (3) in the long duration exercise.

3.3 Statistical Analysis

All results obtained were tested statistically to find out the significance of change in the RMS and median frequency following fatigue. Online software by SISA was used to perform pair-wise t test on the data. T test results done on the RMS and median frequency for the short duration are shown in the table 2 and for the long duration they are indicated in the table 3 below.

Table 2. T Test for median frequency and RMS in the short duration exercise.

	Median Frequency			RMS		
Channel	T	P	Significance	T	P	Significance
1	3.07	0.01	95%	0.37	0.36	28%
2	3.19	0.01	98%	0.67	0.73	74%
3	2.05	0.14	91%	0.49	0.68	69%

Table 3. T Test for median frequency and RMS in the long duration exercise.

	Median Frequency			RMS		
Channel	T	P	Significance	T	P	Significance
1	1.16	0.14	86%	0.39	0.35	64%
2	0.88	0.21	79%	0.74	0.24	76%
3	1.28	0.12	87%	0.33	0.38	62%

4 Discussions

From the results above, it is evident that the changes in the muscle activity as measured using sEMG are entirely different for the long duration and sprint of exercise. RMS of sEMG remained unchanged in both the cases. In the short duration exercise the possible explanation can be that all the motor units were recruited right from the start. The lack of extra motor units to be recruited when needed results in the unchanged RMS. In long duration it can be explained based on the contraction of muscles being sub-maximal and load remains unchanged for the duration of the exercise. This would indicate that the size and activation of motor units required remains unchanged.

The drop in the median frequency was significant in the short duration exercise while not significant for the long duration. The drop in the median frequency for the sEMG is attributed to the synchronisation of motor unit activity and reduction in conduction velocity. The results suggest that during long duration exercise, this may not be the phenomenon and may be explained on the basis that there is sufficient time for the neuromotor system to adapt.

5 Conclusion

The study demonstrates that there is a shift in the spectrum of sEMG due to the onset of muscle fatigue caused due to sprint cycling. Using short-time window at the peak of the muscle activity, it is possible to identify this shift.

The results also indicate that this shift is not evident when the fatigue is a result of long-duration cycling. This indicates that the underlying phenomena due to long duration and sprint cycling appear to be very different. Detailed work that would identify the biochemical changes due to the two causes of fatigue are required to be undertaken.

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