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Changes in SEMG during the Long Duration Cycling Exercise

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***Abstract*— Identification of muscle fatigue using SEMG has always been both desirable and difficult for the engineering and medical community. Changes in SEMG are already established by authors when fatigue occurs as a result of short duration, supramaximal dynamic contraction. But most of the contractions that we have during a days work are not supramaximal and short duration, they are rather continuous and for longer duration and at a sub maximal level. So far reliability of SEMG has not been established for longer duration version of dynamic tasks. This study investigates into these kinds of dynamic contractions where subject performs cyclic dynamic contractions for a long duration. SEMG recordings were analyzed and results were compared with the blood samples and muscle biopsies to validate the results. These invasive techniques are used as current standard and reliable means of identifying muscle fatigue by many sports organizations such as Australian Institute of Sports (AIS), but these techniques are highly invasive, painful, time consuming and expensive. This paper reports a simple signal processing technique to identify muscle fatigue during cyclic activities of muscles such as VL and VM during cycling. Based on the experiments conducted with Nine participants it was found that mechanism of fatigue is different in long duration sub−maximal cyclic exercise as compared to short duration, supramaximal dynamic cycling activity. Same was observed from this present study as the signal processing techniques described by authors in [12] were not successful to identify muscle fatigue in long duration sub−maximal cycling exercise.**

I. INTRODUCTION

Enhancement of human performance is important for improvement of the quality of life, sports and the industry. For this purpose, it is essential to be able to determine the individual threshold at which the onset of fatigue occurs. Fatigue is the point at which the muscle is no longer able to sustain the required force or power output. It is crucial to detect, quantify and analyse the muscle fatigue in occupational, rehabilitation and sports settings.

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 subjects 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 [7]. This leads to the use of electromyogram - a measure of the electrical activity of the muscle - as being an indicator of muscle fatigue.

Invasive markers of high intensity fatigue include depletion of high-energy phosphates including creatine phosphate, accumulation of metabolic bi products including [lactate], [H+] and inorganic phosphate [6]. Altered SR Ca2+ ATPase and Na+, K+-ATPase activity have also been implicated in the fatigue process [11]. Fatigue during prolonged exercise leading to fatigue in 2-3 hours has been associated with depletion of muscle glycogen stores [5]. These measurements are valid and reliable indicators of fatigue but are invasive, and not practical outside the laboratory setting.

Some researchers have attempted to use the electrical activity of muscle and muscle activation using surface electromyogram (SEMG) to study fatigue using surface [1, 9]. SEMG is a result of summation of number of separate motor unit action potential 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.

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 [2]. 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. Several parametric measures of SEMG signal have 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. The authors have used a combination of wavelets and neural networks to reliably classify SEMG with isometric muscle contraction status [4] - a technique that is more reliable for identifying the onset of muscle fatigue [3].

The contraction in the muscles may be due to aerobic or anaerobic origin [6]. The biochemical processes associated with the onset of muscle fatigue changes due to these

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TABLE I

CHANNEL ASSIGNMENT FOR DIFFERENT MUSCLES

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

different causes are believed to be different [10]. This makes the interpretation of SEMG signals from dynamic contractions much more difficult [8]. Authors have devised strategies and techniques of interpretation of SEMG signals in dynamic contraction during short duration, high intensity muscle fatigue [12] and SEMG was established as a good measure of fatigue. As a result of fatigue decrease in frequency contents is observed. This has been attributed to the reduction in the conduction velocity of the muscle fibers and change in muscle activation strategies. However reliability of SEMG have yet to be definitively shown for longer duration. This paper reports an experimental study where changes of SEMG have been measured along with muscle biopsy and blood tests that are considered as reliable standards of muscle fatigue measurement at present during long duration dynamic cyclic exercise that results in muscle fatigue.

II. METHODS\PROCEDURE

Nine (9) moderately active male volunteer participants were recruited (age ranging between 18-40 years) and were medically screened. Written consent was signed by them before participating in the study. For further signal analysis only seven (7) subjects were taken due to data corruption.

A standardized test to fatigue the subjects on a Lode ergo meter with customized software was conducted. All subjects were instructed to cycle for as long as they could at sub maximal level of contraction. Mechanical power output, oxygen consumption and related parameters were measured and have been tabulated in table 2. Subjects were termed fatigue at the end of the cycling. The duration of cycling was different for each participant.The duration of cycling of each subject was normalized for the comparison and analysis purpose.

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 (10 mm), and proprietary electrodes.

Envelop of EMG was computed using moving RMS. The first few and the last few cycles (typically 3) were discarded due to higher level of artifacts and sudden changes occurring

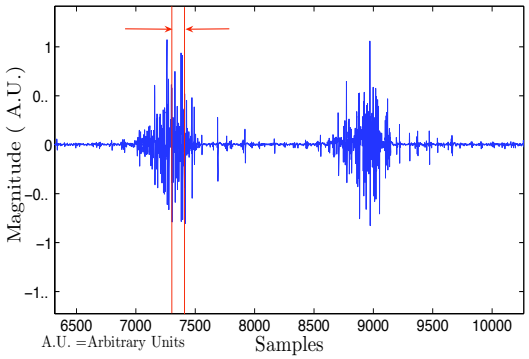

Fig. 1. Windowed Raw Signal (Illustration only) from Vastus Lateralis of one of the subjects

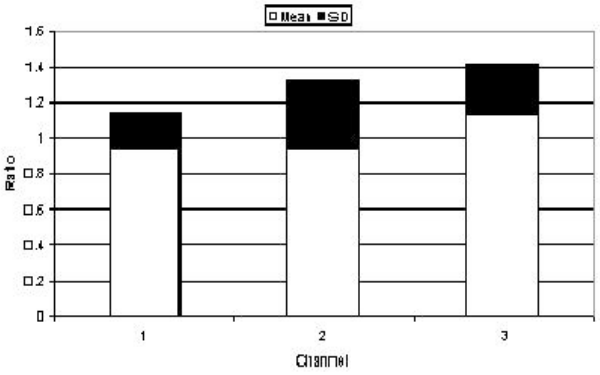

Fig. 2. Normalized RMS of raw signal for the three muscles VL(1),VM(2)and RF(3)

near the start and the end of the exercise. Three cycles near the start and near the end of the exercise (pre and post fatigue conditions) were considered. The peak of each cycle was identified based on moving root mean square (MRMS), and a small section (100 milliseconds) of the raw SEMG data were analyzed (figure 1). Signal processing was done using MATLAB software package. Recordings from only 7 of the 9 participants were analyzed due to corruption of the data files of the other two participants.

The RMS and median frequency of each of the three envelopes representing the pre and post fatigue conditions were computed. 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. Pair-wise 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.

III. RESULTS AND OBSERVATIONS

Figure 2 plots the ratio of normalized RMS of the windowed signal under pre and post fatigue conditions while

TABLE II

SPECIFICATIONS OF THE LONG DURATION EXERCISE

Subjects	Long duration Ride								
	VO2 Peak (ml/kg/min)	Peak Power Output (Watts)	Intensity (63%ppo/70% VO2)	Duration (mins)	O2 Consumption (L/min)				
					20	40	60	80	100
1	53.4	318	200	70	33.9				
2	29.5	263	150	106	26.5	27.5	31.4	32.2	
3	38.9	231	130	94	33.7	33.3	34.0	31.0	
4	53.9	310	195	149	40.4	39.5	42.9	43.0	41.0
5	34.7	220	100	54	31.0				
6	52.6	306	193	121	36.5	37.5	38.0	40.0	40.5
7	46.2	219	138	105	30.2	31.7	31.8	32.2	32.4
8	46.9	287	181	75	33.6	30.7	36.7		
9	51.5	281	177	143	33.0	33.0	34.6	35.8	36.7
Mean	**45.29**	**270.56**	**162.67**	**101.89**	**33.2**	**33.31**	**35.63**	**35.69**	**37.6**
SD	**8.93**	**39.18**	**34.76**	**32.40**	**3.92**	**4.07**	**3.99**	**4.87**	**3.99**
SEM	**2.98**	**13.06**	**11.59**	**10.80**	**1.31**	**1.54**	**1.51**	**1.99**	**2.00**
n	**9**	**9**	**9**	**9**	**9**	**7**	**7**	**6**	**4**

TABLE III

T TEST FOR MEDIAN FREQUENCY AND RMS

Channel	Median Frequency			RMS		
	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%

TABLE IV

T TEST ON BLOOD TEST RESULTS

Parameter	T	P	Remarks
Blood Glucose	1.98	0.04 $*$	during trial
Blood Glucose	2.44	0.02 †	after trial
Blood Lactate	6.73	0.0001 †	during trial
Blood Lactate	4.4	0.001 $*$	after trial

$*$ Decrease is significant

† Increase is significant

TABLE V

BLOOD GLUCOSE BEFORE AND AFTER THE TRIAL

Subject	Rest	Exercise			Post Exercise				
		20	40	60	0	2-3	5-6	10	20
1	7.53	3.08	2.6	3.0	3.0	3.7	4.0	3.3	
2	4.54	3.02	3.4	4.0	5.2	5.8	6.1	6.9	
3	4.17	4.34	3.9	3.5	4.0	4.1	4.4	4.2	4.22
4	4.25	3.85	4.2	4.1	3.6	4.3	4.4	4.2	4.22
5	3.99	6.06	5.2		5.0	5.0	5.2	4.6	4.24
6	3.93	3.43	3.3	3.3	3.5	4.9	5.2	5.0	4.7
7	4.53	4.12	4.1	4.1	4.1	4.8	4.9	4.6	4.07
8	4.56	4.19	3.8	3.9	4.2	4.8	5.2	4.6	4.75
9	3.75	2.71	2.9	3.0	3.2	3.8		3.9	3.43
Mean	**4.58**	**3.87**	**3.7**	**3.6**	**4.0**	**4.6**	**4.9**	**4.6**	**4.33**
SD	**1.14**	**1.00**	**0.7**	**0.4**	**0.7**	**0.6**	**0.6**	**1.0**	**0.51**
SEM	**0.38**	**0.33**	**0.2**	**0.1**	**0.2**	**0.2**	**0.2**	**0.3**	**0.19**
n	**9**	**9**	**9**	**8**	**9**	**9**	**8**	**9**	**7**

figure 3 plots the ratio of normalized median frequency of the windowed signal under pre and post fatigue conditions for the three channels. These parameters are normalized by taking the ratio of post to pre fatigue parameters. A ratio of more than one indicates an increase while a ratio less than one will indicate a decrease in the parameter. The statistical analysis of the results is presented in tables 3 and 4.From the figures and the statistical analysis, it is observed that there is no significant variation of the RMS and median frequency of the recorded SEMG near the start and the end of the long duration cycling exercise.

Variation of the speed of cycling over the duration of the exercise is plotted in figure 4. From the figure it is observed that the speed of cycling reduced towards the end by approximately 13%. This change is significant as confidence level is 95.8% (t = 2.013, p = 0.04).

Table 4 shows the statistical results on the results of the blood test. The blood glucose readings from blood samples taken at regular intervals are tabulated in table 5. From this table it is observed that blood glucose decreased significantly towards the end of the trial but it is quickly restored in the resting time after the exercise trial. Table 6 shows the blood lactate readings. The trend for the change in the blood lactate is opposite to the blood glucose, with an increase near the end of the trial followed by a decrease in the resting period after the trial. This is a definite indication of depletion of energy sources and increase in metabolic bi-products.

The results of the muscle biopsy are tabulated in table 7. From this table, it is observed that muscle lactate increased approximately three folds from non fatigue to fatigue condition, whereas muscle glycogen level decreases sharply from 482 ± 44 to 28 ± 6. Each of these biological markers indicate definite occurrence of muscle fatigue as a result of long duration cycling exercise undertaken by the subjects

IV. DISCUSSIONS AND CONCLUSIONS

Figure 2 and 3 shows that there is no significant change in either RMS or the median frequency. This is also confirmed

TABLE VI

BLOOD LACTATE BEFORE AND AFTER THE TRIAL

Subject	Rest	Exercise			Post Exercise				
		20	40	60	0	2-3	5-6	10	20
1	1.37	3.8	3.3	4.2	5.8	5.6	5.4	4.3	
2	1.79	3.7	4.2	4.3	4.0	3.9	3.6	2.9	
3	1.22	5.8	4.0	2.9	2.6	2.6	2.6	2.4	1.9
4	1.49	3.7	3.3	3.4	2.7	2.5	2.3	2.3	1.9
5	0.68	8.0	8.4		8.1	7.5	7.6	6.1	5.4
6	0.98	3.3	2.8	2.1	4.1	3.9	3.5	3.1	2.5
7	1.5	4.2	3.2	2.3	3.1	2.9	2.7	2.6	2.4
8	0.91	4.6	3.4	2.9	2.9	2.5	2.2	1.9	1.8
9	0.7	1.5	1.4	1.7	2.1	1.8		1.7	1.7
Mean	**1.18**	**4.3**	**3.8**	**3.0**	**3.9**	**3.7**	**3.7**	**3.1**	**2.5**
SD	**0.39**	**1.7**	**1.9**	**0.9**	**1.9**	**1.8**	**1.8**	**1.3**	**1.3**
SEM	**0.13**	**0.6**	**0.6**	**0.3**	**0.6**	**0.6**	**0.6**	**0.4**	**0.4**
n	**9**	**9**	**9**	**8**	**9**	**9**	**8**	**9**	**7**

TABLE VII

MUSCLE BIOPSY RESULTS

	Rest	Post
Creatine	54.6 $\pm$ 2.7	110.3 $\pm$ 4.2 †
CrP	85.4 $\pm$ 5.1	33.1 $\pm$3.7 $*$
Total Cr	140.0 $\pm$ 3.5	143.4 $\pm$ 3.4
ATP	22.3$\pm$ 1.0	19.3 $\pm$ 1.5
Lactate	6.0 $\pm$ 0.7	19.1 $\pm$ 8.8
Glycogen	482 $\pm$ 44	28 $\pm$ 6 $*$

Values are Means $\pm$ SE given in mmol/kg dry muscle; CrP= Creatine Phosphate; Total Cr= (Creatine+ CrP)Significant difference $*$ ($P < 0.001$) and † (P=0.002) between Rest and Post of same test

from the results of the statistical tests in the table 3. Figure 4

shows that there is decrease in the speed of cycling (13%) and the analysis shows that this reduction in speed is statistically significant. The biological markers (blood test and muscle biopsy) indicate the onset of localized muscle fatigue near the end of the cycling, indicating that each of the participants were genuinely fatigued.

The lack of significant change in SEMG indicates that there is no measurable change in muscle activation due to the onset of muscle fatigue at the end of long duration cycling

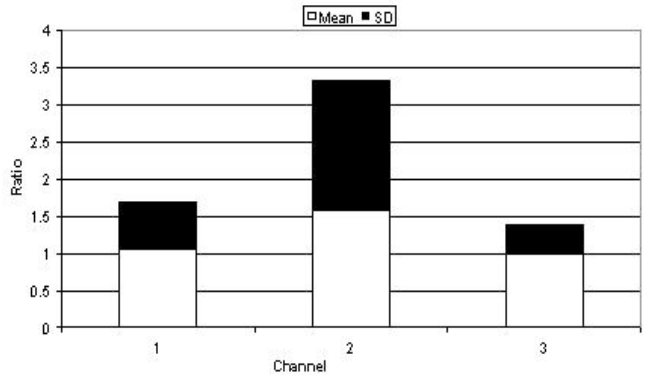

Fig. 3. Normalized Median Frequency of the 100 ms window slice from the three muscles VL(1), VM(2)and RF(3)

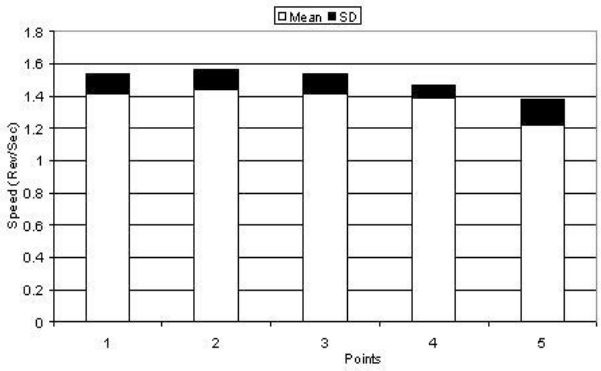

Fig. 4. Change in speed during the duration of cycling. X axis denotes 5 distinct points a quarter of the normalized duration apart. Point 1 being in the start and point 5 in the end.

exercise. The results also indicate that while significant, there is a small drop in the speed of cycling after the onset of muscle fatigue during long duration cycling compared with sprint cycling exercise. These observations indicate that the mechanism that underlies the muscle fatigue for short duration and long duration cycling is different. It also indicates that for long duration cycling exercise, SEMG is not a suitable measure to identify the onset of muscle fatigue.

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