AFFECT OF FATIGUE ON ACTIVATION STRATEGY OF MUSCLES: SEMG STUDY

Vijay P Singh and Dinesh K Kumar

School of Electrical and Computer Engineering, RMIT University, Melbourne, Australia

This research aims to identify the neuromotor changes in muscles associated with fatigue during sprint cycling among 11 recreational cyclists who performed the WAT of 30s. The paper reports experiments conducted where changes in muscle recruitment strategies were studied using multiple recordings of SEMG of lower limb muscles and load was kept constant It is observed that near the end of such an exercise, there is a delay in activation / deactivation of the muscles. This causes the agonist muscles to do negative work during the upward part of the pedal cycle and reduces efficiency. It is suggested that if cyclists activated their muscles for shorter durations after they were fatigued, they may increase their output and reduce the stress on their muscles.

KEY WORDS: SEMG, activation strategy, muscle fatigue, wingate anaerobic test

INTRODUCTION:

Muscle fatigue is the point at which the muscle is no longer able to sustain the required force or power output (Moritani, 1993). Mechanisms of muscle fatigue depend on the exercise conditions (e.g. duration and intensity) and the subject's level of physical fitness (Strojnik et. al., 1998). The decrement in skeletal muscle power output is also related to neural drive reductions (Lepers et. al., 2002). Depending on the exercise conditions, there are different mechanisms associated with the onset of fatigue, from a biochemical process to a neuromotor process (Fitts, 1994).

To better understand muscle fatigue and identify the relationship between various activities and muscle fatigue, controlled pedaling is useful. Pedaling is an ideal human locomotor task to study gross neuromuscular performance as it is a kinematically constrained repetitive movement that can be experimentally manipulated and is analogous to work-loop investigations with a power (shortening) and recovery phase for the majority of the muscles (Neptune et. al., 1997). Surface electromyogram (SEMG) is a non-invasive measure of the muscle activity and is useful to study the angles of activation and deactivation of the muscles, (Neptune et. al., 1997)and to identify the changes in neuromuscular activation (Pah et. al. 2001,Singh et. al.]. The variation of muscle activation strategies can also be argued from the work of Sahaly et al. (2003) and Neptune and Herzog (1999) who have indicated an involvement of the agonist and antagonist relationship and activation strategy for muscle fatigue. This change in activation/ deactivation strategies have been attributed to the speed of cycling by Neptune and Kautz (2001). There appears to be a lack of any study where changes in the activation/ recovery phase of the muscles due to the onset of muscle fatigue have been studied. This paper reports a study where muscle activation/ deactivation during maximal sprint cycling to better understand the phenomena of muscle fatigue.

METHOD:

Theory: Changes in the muscle activation and activation/ deactivation strategies due to the onset of muscle fatigue can reflect the changes in the performance of muscles and changes in muscle activation dynamics. This change may happen due to changes in the muscle fibre conduction velocity or changes in neuromuscular activation strategy.

Deactivation is defined as the point where the muscle turns off. One point of concern would be if there were changes in the angle of rotation when the muscles are deactivated. The expected angle of deactivation of the agnostic muscles responsible for pushing the pedal is less than half the cycle, and if this changes and extends beyond half the cycle, the muscle's work would be counterproductive.The other point of interest is the point of peak activation. Peak activation is defined as the largest activity of muscle during a cycle. At the onset of muscle fatigue, it is expected that signal near the peak activation of the muscle would be first to be effected. This paper reports the analysis of the changes due to muscle fatigue of the peak activation and muscle deactivation point for the three-quadriceps muscles, the agonist during the first half of the cycle and the two calf muscles being the antagonists during the second half. SEMG has been used to determine the muscle activation and deactivation strategies.

Data Collection: SEMG data was collected from 11 participants. Corruption of SEMG data occurred for 4 participants and analysis was completed for 7 participants. The WAT (30 seconds) is a supra maximal cyclic sprint test that results in the development of sudden onset non-psychological muscle fatigue. High speed pedalling provides a platform for measuring changes in activation strategies. Power and speed of cycling were also recorded during the test to determine changes in performance associated with these factors. Neuromotor activation was studied using multiple channel surface EMG. To measure the speed of rotation (cycling) and determine the angle of the rotation at any time during the recording, four micro switches were installed on the pedal (12, 3, 6 and 9^{O}'clock) and output from these was recorded along with five channels of SEMG. The subject was termed as 'fatigued' when the power output dropped by greater than 33% (De Luca, 1984)

Five sets (pairs) of Delsys (Boston, MA, USA) (proprietary) electrodes were placed on the skin of the participant's lower limb overlying the muscles under investigation (Table 1). The ground electrode was placed on the volar aspect of the wrist. The first and the last cycle of the recordings were discarded because of sudden changes taking place during these segments. Windowed RMS was computed for the SEMG to identify the envelopes of activity for each cycle. The total duration of the sprint was divided into 5 equal sections, 1 corresponding to the start, and 5 to the end of the sprint. Preliminary inspection of the data indicated that peak speed and power occurred at point 2. Using the envelopes identified, three cycles occurring just before point 2 and another three at the end – point 5 (after discarding the first and the last) of the exercise, representing pre and post fatigue conditions were considered. The peak of each cycle was identified by detecting the maximum value of the moving root mean square (MRMS) within the activity burst associated with one pedal cycle. Using this criterion for peak identification we can eliminate the ambiguity in determining the peak in multi-modal bursts of activity (Figure 1).

Table 1: Channel Assignment for Different Muscles

Channel	Muscle
1	Vastus lateralis (outside thigh muscle - front)
2	Vastus medialis (inside thigh muscle - front)
3	Rectus femoris (middle thigh muscle - front)
4	Medial gastrocnemius (inside calf muscle)
5	Lateral gastrocnemius (outside calf muscle)

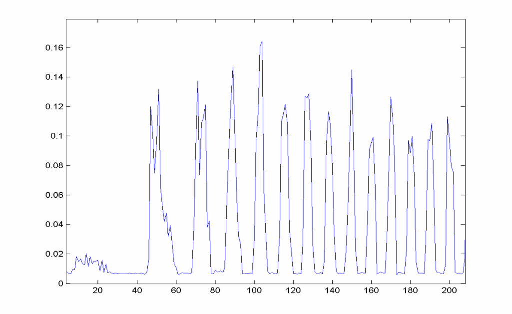

Figure 1 Envelop Of SEMG Signal

Table 2: t test (increase in angle of peak activation/deactivation)

	Peak Activation		Deactivation	
Channel	t	p	t	p
1	1.825	0.06	2.78	0.016
2	3.319	0.008	3.83	0.004
3	4.405	0.002	3.20	0.009
4	2.454	0.025	4.90	0.001
5	0.154	0.56	1.28	0.125

Angle of peak activation/deactivation was calculated by first taking the absolute time topeak activation/ deactivation. Absolute time was calculated by counting the number of samples from the start of the cycle (12 – noon) and dividing this by the sampling rate. To account for the change in speed of cycling the time to peak activation/ deactivation (from 12 o'clock) was multiplied with the speed of cycling at that time to obtain the angular delay as a fraction of the cycle at a particular instance. Data from all participants were pooled and statistical analysis was done using the online statistical software, SISA. Changes in parameters were tested using the paired Student's *t*-test. The results of this are tabulated and analysis presented along with the observations and discussion. A correlation analysis was conducted between the speed of cycling and the power output to identify the relationship between the two. Pearson correlation coefficients were calculated on the five points of interest for all subjects. Statistical significance was accepted at $p<0.05$.

RESULTS:

The angles (in terms of fraction of a revolution) at which each of the five muscles reach the peak of activation at the start and near the end of the exercise protocol is indicated in table 3. A significant increase in the time to peak activation for VM, RF, and MG ($p<0.05$) is observed (see also Table 2). For all muscles except LG, ratio values were greater than 1 suggesting an increase in the time to peak activation at fatigue.

Table 3: Angle of Peak Activation and Deactivation (Fraction of full cycle)

	Fraction of cycle (Peak Activation)						Fraction of cycle (Deactivation)					
	Pre Fatigue		Post Fatigue		Ratio (Post/Pre)		Pre Fatigue		Post Fatigue		Ratio (Post/Pre)	
Channel	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	0.23	0.11	0.30	0.07	1.35	0.72	0.52	0.11	0.56	0.11	1.08	0.07
2	0.25	0.08	0.31	0.09	1.29	0.34	0.50	0.09	0.56	0.11	1.13	0.07
3	0.16	0.08	0.24	0.09	1.82	0.88	0.46	0.10	0.54	0.12	1.17	0.15
4	0.54	0.08	0.69	0.10	1.32	0.37	0.88	0.09	0.93	0.10	1.05	0.02
5	0.51	0.13	0.51	0.17	0.97	0.22	0.86	0.08	0.88	0.07	1.01	0.06

The angle at which muscles deactivate is indicated in table 3. There was a significant increase in the deactivation time for all muscles except LG (see also Table 2). This table illustrates pre and post-fatigue values and the ratio of these values. For all the muscles the ratio values were greater than 1 suggesting an increase in the time to deactivation at fatigue. The deactivation time for the three representative agonist muscles (quadriceps) at fatigue is greater than 0.5 (half cycle) indicating that these muscles continue to be active beyond the half cycle.

DISCUSSION:

The aim of this investigation was to identify changes in activation strategies and performance of lower limb muscles with the onset of fatigue induced by fatiguing sprint cycling. Our results indicated that cycling speed varies from the start to the end of the sprint test. It is maximum at the end of the 1st quarter (2.8 revolutions/ second), after which it steadily decreases to 1.7 revolutions per second just before the end of the sprint. The change in the angle at which peak muscle activation occurs is indicated in table 3. From this figure and Table 2, it is observed that the angle near the end of the test (when the muscles are fatigued) is significantly larger than at the start when the muscles were not fatigued. This angle increases after the onset of muscle fatigue.

There is a similar observation for the deactivation angle. From table 3, it is observed that the angle of deactivation of the three-quadriceps muscle that is VL, VM and RF increases and this increase is significant ($p<0.05$) (table 2). The results show that these muscles after fatigue remain active beyond the half cycle (0.5), thus acting to push the pedal downwards when the pedal is actually moving upwards. During this part of the cycle, the muscle's work is counter-productive. During this section of the cycle, the muscles work against themselves, or, are responsible for negative work and behave antagonistic and actually slow pedalling. This suggests that if the cyclist were able to reduce the duration of muscle contraction, they would actually increase their output. Reduction in the speed of conduction of action potentials in muscle fibres after fatigue is well established (De Luca, 1984).We suggest the explanation for the increase in activation and deactivation angles is caused because of the reduction in the conduction velocity of muscle fibres. The quadriceps muscles are therefore active during the half of the cycle when the corresponding foot is moving upwards, and hence results in the generation of negative work. The limb that is travelling upwards also works against the limb that is pushing the pedal downwards.

Another observation is that this change in the muscle deactivation strategy happens even though the speed of cycling is reducing that was confirmed for any deviation using statistical analysis reported in table 2. This is in contrast to the observations of Neptune and Herzog (1999) who suggested that the increase in negative work was related to an increase in the speed of pedalling beyond 2 cycles per second. Our observations suggest that the increase in the negative work is also occurring due to the onset of muscle fatigue.

CONCLUSIONS:

From this study we conclude that muscle fatigue associated with the sprint test is a result of changes in the muscle and muscle activation strategies. One explanation of the changes observed of SEMG and activation/ deactivation angles is that there is a reduction in the conduction velocity of the muscle fibres due to the onset of muscle fatigue from sprint cycling. It has been observed that with the onset of muscle fatigue, there is an increase in the crank angles corresponding to muscle peak activation and also for muscle deactivation. Of particular concern is that after the onset of fatigue, the deactivation angle goes past the 6 o'clock position, and the muscle is active when the associated foot is pedalling upwards. This causes asynchronisation between the muscles of the two legs and the muscles of the leg corresponding to the foot that is moving upwards remain active for a short duration and results in the generation of negative force and negative work. Based on the well-accepted findings of De Luca (1984) and others that spectral compression of EMG due to muscle fatigue is accompanied with reduction in the conduction velocity of muscle fibres, the authors propose to explain the increase in activation/ deactivation time by attributing it to the reduction in muscle fibre conduction velocity. We conclude that this increase in the activation/ deactivation angles causes negative force and work. It is also observed that during the sprint exercise the untrained cyclists generate negative work after the onset of fatigue by extending their muscle activation beyond the half cycle mark. This suggests that if the subjects could be trained to reduce the overall muscle activation period after the onset of muscle fatigue, this would increase in the overall output. There is need to test this on trained cyclists to determine the difference between the two categories.

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