研究摘要 RESEARCH HIGHLIGHTS

Wavelet Analysis of Muscle Fatigue Patterns in a 5-minute Maximal Cycling Effort

Raymond C.H. So[1,2], Joseph K.-F. Ng[1], Ringo W.K. Lam[3], K.K. Lo[2], Gabriel Y.F. Ng[1]
[1]Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, HONG KONG
[2]Hong Kong Sports Institute, Sha Tin, HONG KONG
[3]Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hung Hom, HONG KONG

Purpose Adaptive strategies of muscle recruitment may serve to minimize energy use in fatigued condition. An individual could adopt a variety of movement sequence in order to continue with the task. To reveal the muscle recruitment pattern during exercise, surface EMG (sEMG) is a useful tool because it is non-invasive and all the information could be recorded continuously during the course of exercise. Therefore the aim of this study was to monitor the alteration of activation period and activity level of the muscles by sEMG wavelet analysis and cross-correlation analysis during maximal cycling exercise. Moreover, sEMG analysis may applied to other sporting and occupational tasks for identifying the specific muscle fatigue pattern, so as to develop a muscle training program to enhance performance and reduce injury.

Method Eight young male cyclists volunteered for this study. After warm up on a cycling ergometer, they ride at 95% of individual VO_{2max} power at 90 rev min-1 for 5 minutes. Surface EMG (sEMG) data were recorded continuously during the exercise from gluteus maximus, rectus femoris, vastus medialis, vastus lateralis, biceps femoris, semitendinosus, tibialis anterior and medial gastrocnemius of the subjects' right leg. The sEMG data were then wavelet transformed. Cross-correlation was used to quantify the phase-shift or delay of the power intensity of the wavelet data in each cycling cycle.

Analysis of sEMG data

Wavelet transform

von Tscharner (2000) explained that the wavelet transform decomposed the sEMG signals into time and frequency using a set of non-linearly scaled wavelets and the author recommended a set of 11 wavelet scales to analyze the sEMG as it can cover the frequency range of the sEMG signals. Each wavelet domain was characterized by its center frequency, band width and time resolution. Each wavelet was then convolved with the sEMG. Then the power intensity pattern for each wavelet domain within a pedaling cycle, called a wavelet domain, was obtained. Although large amount of wavelet data were recorded in the 11 domains, only the one with center frequency at 92.4Hz and band width at 35.2Hz was selected, as this domain was found to have the highest reliability to document the power intensity shift in relation to muscle fatigue.


Fig 1: Surface EMG was recorded continuously from 8 muscles of the right leg during the 5-minute cycling exercise

Cross-correlation

Cross-correlation was then employed to quantify the phase shift of the power intensity of wavelet data between time points. The confidence interval of the peak cross-correlation was calculated for statistical analysis of the correlation coefficient (α set at 0.05), with time point 1 being defined as the base level.

Statistics

Descriptive statistics were generated for subjects characteristics as well as kinetic, metabolic and sEMG values. Paired t-test was used to examine the pre- and post-cycling results. Statistical significance was established at a=0.05. Linear regression coefficients were calculated for each subject to determine the relationship between the sEMG activity shift and the increase of exercise time. The phase shift at time point 75 was calculated by the individual linear regression equation. The group average of this result was then tested by independent t-test. Similar method was used to establish the relationship between the change of power intensity of the wavelet data with the exercise time.

Note

(a) *Due to the high variance in the sEMG data of the first 30 seconds and the last 15 seconds of the test, data from these two periods were discarded. From the 31st second to the 285th second, every 5 cycling cycles were averaged into one cycle to present one time point and this resulted in 75 cycling time data points.*

(b) *The top dead centre was defined as 0° and increase in clockwise direction.*

Result

Table 1. The degree shift of the power intensity of wavelet data determined by the linear regression analysis for all the assessed muscles after 5 mins cycling.

Muscle	Slope*	No. of subject with p value < 0.05	Degree shift at the last time point	p value
Gluteus Maximus	0.0021	7	1.6°	0.15
Rectus Femoris	0.0050	5	3.8°	0.10
Vastus Medialis	0.0036	4	2.7°	0.35
Vastus Lateralis	0.0037	3	2.8°	0.09
Biceps Femoris	0.0042	5	-3.2°	0.51
Semitendinosus	0.0006	3	-0.5°	0.72
Tibialis Anterior	0.0044	3	3.3°	0.16
Medial Gastrocnemius	0.0163	6	12.2°	**0.02**

Table 2. The percentage change of the power intensity of wavelet data determined by the linear regression analysis for all the assessed muscles after 5 mins cycling.

Muscle	Constant	Slope*	No. of subject with p value < 0.05	Percentage difference at the final time point	p value
Gluteus Maximus	11.0719	0.0403	6	29.5%	0.12
Rectus Femoris	11.1541	0.0585	5	39.5%	0.03
Vastus Medialis	14.6934	-0.0083	1	-4.0%	0.36
Vastus Lateralis	13.2792	0.0118	6	5.3%	0.44
Biceps Femoris	11.4788	0.0210	6	14.1%	0.65
Semitendinosus	13.3964	0.0012	5	-1.9%	0.83
Tibialis Anterior	12.2434	0.0101	3	6.3%	0.45
Medial Gastrocnemius	13.7409	-0.0264	6	-14.4%	**0.004**

Results indicated that most muscles had delay activity in reference to a complete cycle as exercise time increased but the extent was different between muscles. The gluteus maximus, rectus femoris, vastus medialis, vastus lateralis and tibialis anterior had a delay ranged from 1.6° to 3.8°. Medial gastrocnemius showed the largest delay of 12.2°. Biceps femoris and semitendinosus had no shifting and it activated earlier in the sEMG activities respectively (Table 1). Although significant trend of increasing or decreasing were observed in most of the subjects, except vastus medialis and tibialis anterior, significant group difference at time point 75 as in comparison with time point 1 were only noted in rectus femoris and medial gastrocnemius (Table 2). Both biarticular muscles, namely, medial gastrocnemius and rectus femoris, were found to be more sensitive to fatigue than other muscles tested. Therefore, training both medial gastrocnemius and rectus femoris might benefit the cycling performance.

Conclusion During a 5-minute maximal cycling exercise, the subjects would alternate the pattern of muscle activation to minimize muscle fatigue. As fatigue developed, most muscles had some delay in their onset time. Medial gastrocnemius and rectus femoris were found to be more sensitive to fatigue than other muscles tested, this might be related to its biarticular nature. Therefore, training both muscles might benefit the cycling performance.

References

1. *Chapman, A.R., Vicenzino, B., Blanch, P., Knox, J.J. & Hodges, P.W. (2006) Leg muscle recruitment in highly trained cyclists. Journal of Sports Sciences, 47(2):115-124.*
2. *von Tscharner, V. (2000) Intensity analysis in time-frequency space of surface myoelectric signals by wavelets of specified resolution. Journal of Electromyography and Kinesiology, 10:433-445.*
3. *Wakeling, J.M., Pascual, S.A., Nigg, B.M. & von Tscharner, V. (2001) Surface EMG shows distinct populations of muscle activity when measured during sustained sub-maximal exercise. European Journal of Applied Physiology, 86:40-47.*
4. *Billaut, F. Basset, F.A. & Falgairette, G. (2005) Muscle coordination changes during intermittent cycling sprints. Neuroscience Letters, 380:265-269.*
5. *So RCH, Ng JK-F, Lam RWK, Lo KK, Ng GYF (2008) EMG wavelet analysis of quadriceps muscle during repeated knee extension movement. Medicine and Science in Sports and Exercise (submitted for publication).*
6. *Li, L. & Caldwell, G.E. (1999) Coefficient of cross correlation and the time domain correspondence. Journal of Electromyography and Kinesiology, 9:385-389.*

March 2009

HONG KONG
SPORTS INSTITUTE
香港體育學院

RESEARCH AND SPORTS INFORMATION SECTION
Hong Kong Sports Institute, 2 On Chun Street, Ma On Shan, Sha Tin, New Territories, Hong Kong
Tel: (852) 2681 6888 Fax : (852) 2695 4555 Email: rsi@hksi.org.hk Homepage: http://www.hksi.org.hk