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EMG Power Spectrum Analysis of the Medial Gastrocnemius and the Soleus Under the Fatigued Condition

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국문요약

피로조건하에서의 내측 장딴지근과 가자미근의 근전도 스펙트럼 분석

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연구목적 이 연구의 목적은 피로유발수축후 장딴지근과 가자미근의 근전도 power spectrum 중앙경향치를 비교 검사하는 것이다. **실험대상** 열 여섯명의 자원자(남자 10, 여자 6)를 대상으로 하였다. 남자 대상자의 연령범위는 25세에서 33세(평균 28.6±2.5)였고 여자 대상자의 연령범위는 26세에서 31세(27.8±1.9)였다. **실험방법** 실험대상자는 피로유발수축직후 50% 최대등척성근수축을 수행하였다. 자료수집과 분석을 위해 LabVIEW 소프트웨어를 사용하였다, **결과** t-검정결과 내측 장딴지근에서는 피로유발수축후 주파수의 중위값과 평균이 통계적으로 유의하게 감소하였으나 가자미근에서는 통계적으로 유의한 차이가 없었다. t-검정결과 두 근육간 주파수 감소의 차이는 통계적으로 유의한 차이가 있었다. **토의 및 결론** 이 결과들은 피로유발수축후 근전도 power spectrum 중앙경향치가 저주파대역으로 감소함을 나타내었다. 이 연구는 중앙주파수와 평균주파수가 피로지수로서의 신뢰도와 타당도가 뛰어나며 객관적 측정과 훈련효과 평가로 사용할수 있음을 보였다.

핵심단어: 근전도 스펙트럼 분석; 피로; 중앙주파수; 평균주파수.

Introduction

It has been well known that the EMG power spectrum declines to a lower frequency domain during prolonged isometric contraction (Ament et al, 1993) This frequency decline can be interpreted as a sign of localized muscle fatigue and can be objectively measured by EMG power spectrum statistics: the median frequency and mean frequency (De Luca, 1984). The median power frequency is the frequency where the spectrum is divided in two parts of equal power (Bilodeu et al, 1995). The mean power frequency is the average of all frequencies. The development of localized muscle fatigue can be measured by the collected EMG signal of the power spectrum (Biederman, 1991; Hermens et al, 1992; Merletti et al, 1984). Several factors that influence this development of localized muscle fatigue are the force level, muscle length, muscle temperature, circulation, and muscle fiber composition (Arendt-Nielsen and Sinkjaer, 1991).

The power spectrum analysis utilizes the frequency domain processing for information content. The Fourier transform procedure is used to transform the time domain EMG signals into the frequency domain data (Sodrberg 1992). With a sustained muscle contraction, the low frequency components of the signal gradually increase while the high frequency components decrease. These frequency changes produce a shift in the power spectrum toward the lower frequencies. There are other factors that contribute to the frequency shift. Lindstrom and Petersen (1983) suggested the combination of synchronization and desynchronization of motor unit firing as a possible cause of frequency shift. Arendt-Nielsen and Mills (1985) suggested that the decline of muscle fiber conduction velocity may result in frequency shift. Kadefors and his co-workers (1983) showed that the shift of frequency might be caused by intramuscular pressure changes.

Recently many authors have used two central tendency parameters extensively to measure localized muscle fatigue in the power spectrum analysis, i.e. median and mean frequency. Ament and his associates (1993) investigated the median power frequency of the calf muscles during dynamic exercise as a sign of local muscle fatigue. Komi and Tesch (1979) compared the frequency shift in dynamic isokinetic exercise with muscle fiber composition. They found a larger shift in fast-twitch fiber. Arendt-Nielsen and Sinkjaer (1991) quantified dynamic muscle fatigue using the mean power frequency of the lower extremities and the kinematic parameters during uphill walking. Naeije and Zorn (1982) studied human biceps brachii muscle fatigue using the mean power frequency. Fatigue of the paraspinal muscles using a median frequency has been studied by Dolan, and his colleagues (1995), and by Van Dieen and her colleagues (1993).

Bilodeau and his co-workers (1994) demonstrated the reliability of the mean power frequency and the median frequency of the power spectral analysis obtained during isometric contraction. The results indicated that the median power frequency and the mean frequency were reliable measures across sessions. The long-term reliability of the EMG power spectrum analysis for the paraspinal muscles was studied by Thomson and Biedermann (1993). The test/retest variation for the fatigue parameter was found to be within the range of variability using a confidence interval method.

In this present study, the triceps surae muscle will be under fatigue conditions to measure and compare the EMG power spectrum central tendency. The triceps surae muscle is suited for such an analysis because it is active in the same movement as the main plantar flexors, and it is different in muscle fiber type composition. The triceps surae muscle consists of the medial and lateral heads of the gastrocnemius muscle and the soleus muscle. The soleus muscle has a predominance of type I (slow-twitch) muscle fibers (70-100%) and the gastrocnemius muscle consists of >50% type II (fast-twitch) muscle fibers (Bilodeus et al, 1994). Type I muscle fibers are slow-contracting and fatigue-resistant (Kimura, 1989; Nordin and Frankel, 1989). Because of the higher proportion of type I muscle fibers and lower proportion of type II fibers in the soleus muscle, a less pronounced decline of the median and mean frequency to the lower frequency domain was expected for the soleus muscle.

The purpose of this study was to compare the EMG power spectrum central tendencies of the medial gastrocnemius and soleus before and after the fatigue contraction in order to provide greater understanding of the triceps surae muscle fatigue phenomena Since physical therapists work to restore the strength and endurance in muscles during the rehabilitation period, reliable and valid fatigue indicators are required for objective measurement and training effect assessment. The central tendencies (median and mean frequency) of the EMG power spectrum can serve this purpose as a measurable parameter (Enoka, 1994).

Materials and Methods

Subjects

Male and female volunteers were recruited through the New York University, the Department of Physical Therapy. A sample of 10 men and 6 women, aged 25 to 33, participated in this study (Table 1). A screening interview was conducted by the researcher to assess each subject's ability to participate in the study. Subjects were included if they were free of any orthopedic or neurologic problems that would impair their ability to perform a 50% of MVIC; had normal ankle range of motion; had adequate motor control; and had the endurance to perform a contraction of 66 seconds of 50% of the MVIC Subjects who were not excluded by self-report were further screened by the researcher to rule out any orthopedic or neurologic problems The subjects then read the consent form and signed it prior to their participation.

Procedures for Data Collection

Testing was performed in the NYU research laboratory located at 342 East 26th Street; Room 200-A, New York, New York

Table 1. Subject Characteristics (N=16)

		Males (n_1=10)	Females (n_2=6)
Age (yr)	Mean ± SD	28.6 ± 2.5	27.8 ± 1.9
	Range	25 ~ 33	26 ~ 31
Height (cm)	Mean ± SD	169.7 ± 5.5	160.8 ± 6.3
	Range	162.6 ~ 179.0	152.4 ~ 170.0
Weight (kg)	Mean ± SD	72.9 ± 4.7	49.4 ± 50.9
	Range	67.5 ~ 81.0	42.8 ~ 55.0

The temperature of the laboratory was 75 degrees. The laboratory was clean, well lighted, and free from extraneous noises.

The subject was required to read and sign a consent form (see Appendix A). A screening interview was conducted by the investigator to assess the subject's ability to participate in the study. The placements of the pre-amplified surface electrodes were determined by finding the midpoint position of the soleus muscle between the head of the fibula and the tuberosity of the calcaneus and the upper one third proximal position of the medial gastrocnemius between the medial knee joint space and the tuberosity of the calcaneus and then marking them with an ink pen. The subject's skin was prepared by cleaning the skin with alcohol, and lightly rubbing the skin with a light abrasive. Conductive gel was put in the holes in the double-sided foam adhesive tape over the electrode. Each electrode was attached parallel to the muscle fibers on the prepared sites. The reference electrode was attached on the patella. To prevent movement artifact, the electrical leads were placed on the skin using adhesive tape. The subject was seated in the Biodex chair with the trunk and pelvis stabilized by the non-elastic straps. The knee joint was maintained in full extension with the ankle stabilized at neutral position to ensure a constant muscle length throughout the experimental session and to prevent any proximal compensatory muscle contraction. The ankle joint was aligned with the axis of rotation of the Biodex dynamometer. This was the standardized position for data collection. The voltmeter was attached to the Biodex interface and 15 Volts was determined as the output unit. The subject was given a demonstration of and verbal instructions in performance of a maximal voluntary isometric contraction (MVIC) for the dominant ankle. The subject then was asked to perform the MVIC for plantar flexion for 6 seconds as a reference contraction, and the maximal voltage on the voltmeter was marked. This maximal voltage served as the 100% MVIC for the normalization procedure. The voltmeter was marked at 50% of maximal value as the preset target voltage. The subject viewed the marked voltage value in voltmeter and performed the 50% of the MVIC for six seconds. The subject was instructed to match the target on the voltmeter during the 50% of MVIC. The six seconds of 50% of MVIC data were collected using a named file, 2CHANEMG.VI and were saved for determination of mean and median power frequencies.

Following the resting period of 2 minutes, the subject was asked to perform the same procedure for 66 seconds. At the end of 60 seconds, while the subject continued to maintain the 50% of MVIC, the last six seconds of data were collected using a named file, 2CHANEMG.VI and were saved for determination of the mean and median power frequencies. A named file, PSPECX2.VI. was used to determine these frequencies as a measure of central tendency.

The median and mean frequencies of the medial gastrocnemius and the soleus muscles were compared to determine if there were statistically significant differences between the central tendencies before and after the fatigue contraction and then to determine which muscle produced the greater frequency shift towards the lower frequency domain under fatigue condition.

Measurement and Evaluation Instruments

The electromyographic system, EMG-544 measured the MVIC of the medial gastrocnemius and soleus muscles The electrode assemblies, containing circuitry for pre-amplification in a plastic enclosure with a gain of 35, were used for the two muscles. Each assembly held two silver-silver chloride electrodes, which were 8 ㎜ in diameter with a 20 ㎜ distance between centers. The adjustable gain was 20 ㎑. The sampling rate for data collection was 1024. A bandpass filter with a low frequency cutoff of 20 Hz and a high frequency cutoff of 500 Hz was used to increase the signal to noise ratio.

The LabVIEW software was the graphical programming language for the collection, manipulation and processing of data collected from the electromyographic system. The windows v3.11 version of LabVIEW v3.11 was used. Two programs were created and used: (1) 2CHANEMG.VI for EMG data collection; and (2) PSPECX2.VI which converted the time domain EMG signal into frequency domain data for determination of the median and mean frequencies.

The goniometer was used to assure the full extension of the knee and the neutral position of the ankle for the standardized position of the dominant leg.

A voltmeter was used to obtain the MVIC voltage value for the reference contraction to determine the 50% of MVIC value for normalization and to serve as a visual target for data collection. A stop-watch was used for exact timing for data collection. A tape measurement in centimeters was used to measure the distance between reference parts for surface electrode assembly placement.

Data Analysis

T-tests were used with an alpha level of .05 to determine statistical significance for the median and mean power frequency decreases in the medial gastrocnemius and the soleus muscles after the fatigue contraction and the difference in frequency decreases between the two muscles.

Results

The mean values for median and mean power frequencies before and after the fatiguing contraction of medial gastrocnemius and soleus muscles are presented in Table 2. The mean and standard deviation of the median power frequency value decreased from 185.5±81.3 Hz to 178.2±82.8 Hz after the fatiguing contraction for the medial gastrocnemius. The mean and standard deviation of the median power frequency value decreased from 75.5 ±59.8 Hz to 75.2±57.3 Hz after the fatigue contraction for the soleus. The mean and standard deviation of the mean power frequency value decreased from 216.7±31.9 Hz to 210.4±37.2 Hz after the fatigue contraction for the medial gastrocnemius. The mean and standard deviation of the mean power frequency value decreased from 168.8±31.2 Hz to 167.4±31.6 Hz after the fatiguing contraction for the soleus.

The decrease for median and mean power frequencies in the medial gastrocnemius was significant ($p<.05$). The decrease in the soleus was not significant ($p<.05$). The median power frequency decreased with a mean of 7.3 Hz (4.0%) for the medial the medial gastrocnemius, and 1.6 Hz (1.0%) for the soleus. Significant differences were found between the frequency decreases in the medial gastrocnemius and the soleus ($p<.05$).

Table 2. Mean values for median and mean power frequencies (Hz)

Muscle	Median power frequency before contraction	Median power frequency after contraction	Mean power frequency before contraction	Mean power frequency after contraction
Medial gastrocnemius	185.5±81.3	178.2±82.8	216.7±31.9	210.4±37.2
Soleus	75.5±59.8	75.2±57.3	168.8±31.2	167.4±31.6

Discussion

The median and mean frequencies of the medial gastrocnemius and soleus muscle were decreased to a lower domain after the fatiguing contraction. In the medial gastrocnemius muscle, a greater frequency decrease was noted as compared to the decrease in the soleus muscle. These result supported the investigation of Ament and his associates who collected isometric EMG data for 5~10 seconds after running an uphill treadmill until the moment of exhaustion. They found a median frequency decrease for the medial gastrocnemius to be 16.7 Hz and for the soleus muscle to be 9.5 Hz as compared with 7.3 Hz and .2 Hz in this experiment. The differences in values may stem from the different method of inducing a muscle fatigue. In this experiment muscle fatigue was induced by gastrocnemius, and .2 Hz (.3%) for the soleus. The mean power frequency decreased with a mean of 6.3 Hz (2.9%) for 50% of MVIC for a period of 66 seconds and in the experiment of Ament and his associates fatigue was induced by ruing on a treadmill until the moment of exhaustion.

The limitations of this study maybe the result of the following: (1) This study examined only subjects who were free of orthopedic and neurologic problems; therefore, the finding in this study can not be generalized for the all population; (2) Some subjects, especially male subjects, did not demonstrate the frequency shifts possibly the result of the relatively short period of fatigue contraction and/or 50% of MVIC normalization procedure; and (3) There was a possibility of cross-talk during the EMG data collection as a result of the soleus location immediately anterior to the gastrocnemius.

The result of this present study indicate that the power spectrum of the EMG signal is sensitive to the different muscle fiber types as fount in the medial gastrocnemius and the soleus muscles. Further research is needed to differentiate the behavior of the median power frequency and mean power frequency, to incorporate the effect of fiber diameter and skinfold thickness, and to include patient subjects for the fatigue study.

Conclusion

In this experiment the median and mean frequencies of the medial gastrocnemius and soleus muscles were investigated Power spectrum analysis showed a significant frequency shifts in the medial gastrocnemius and a non-significant shift in the soleus after the fatigue contraction. Significant difference were found between the frequency shifts in the medial gastrocnemius and the soleus muscles. This study justified the use of the median and mean frequencies as reliable and valid fatigue indicators which may be added to the examination test and measures for physical therapy practice.

References

Ament W, Bonga GJ, Hof AL, Verkerke GJ. EMG Median power frequency in an exhausting exercise. J Electromyogr Kinesiol. 1993;3(4):214-220.

Arendt-Nielsen L, Mills KR. The relationship between mean power frequency of the EMG spectrum and muscle fiber velocity. Electroenceph Clin Neurophysiol. 1985;60:130-134.

Arendt-Nielsen L, Sinkjaer T. Quantification of human dynamic muscle fatigue by electromyography and kinematic profiles. J Electromyogi kinesiol. 1991;1(1):1-8.

Biederman HJ. A method for assessing the equivalence of repeated measures of muscle fatigue rates estimated from EMG power spectrum analysis. J Electromogr Kinesiol. 1991;1(4):288-292.

Bilodeau M. EMG power spectrum of elbow extensors. A reliability study. Electromyography & Clinical Neurophysiology. 1994;34:149-158.

Bilodeau M, Cinera M, Gervais S, Arsenault AB, Gravel D, Lepage Y, McKinley P. Changes in the electromyographic spectrum power distribution caused by a progressive increase in the force level. Eur J Appi Physiol. 1995;71:113-123.

Bilodeau M, Goulet C, Nadeau S, Arsenault AB, Gravel D. Comparison of the EMG power spectrum of the human soleus and gastrocnemius muscles. Eur J Appl Physiol 1994;68:395-401.

De Luca CJ. Myoelectric manifestations of localized muscular fatigue in humans. Crit Rev Biomed Eng. 1984;11:251-279.

Dolan P, Mannion AF, Adams MA. Fatigue of the erector spinae muscles. A quantitative assessment using frequency banding of the surface electromyography signal. Spine. 1995;20:149-159.

Enoka RM. Neuromechanical basis of kinesiology, 2nd ed. Champaign, IL. Human Kinetics, 1994.

Hermens HJ, Bruggen TAM, Baten CTM, Rutten WLC, Boom HBK. The median frequency of the surface EMG power spectrum in relation to motor unit firing and action potential properties. J

Electromyogr Kinesiol. 1992;2(1):15-25.

Kadefors R, Arvidsson A, Herberts P, et al. EMG data processing in ergonomics with emphasis on shoulder muscle load. In: Desmedt JE, ed. Computer-Aided Electromyograghy: Progress in clinical neurophysiology, Basel, Switzerland, Karger, 1983;10:273-286.

Kimura J. Electrodiagnosis in Diseases of Nerve and Muscle: Principles and practice. 2nd ed. Philadelphia, F.A. Davis Co., 1989.

Komi PV, Tesch P. EMG frequency spectrum, muscle structure, and fatigue during dynamic contractions in man. Eur J Physiol. 1979;42:41-50.

Lindstrom L, Petersen I. Power spectrum analysis of EMG signals and its application. In: Desmedt JE, ed. Computer Aided Electromyography: Progress in clinical neurophysiology, Basel, Switzerland, Karger, 1983;10:5.

Merletti R, Sabbahi MA, De Luca CJ. Median frequency of the myoelectric signal: Effects of muscle ischemia and cooling. Eur J Appl Physiol. 1984;52: 258-265.

Naeije M, Zorn H. Relation between EMG power spectrum shifts and muscle fiber action potential conduction velocity changes during local muscular fatigue in man. J Apply Physiol. 1982;50:23-33.

Nordin M, Frankel VH. Basic biomechanics of the musculoskeletal system. 2nd ed. Philadelphia, London, Lea & Febiger, 1989.

Soderberg GL. Selected Topics in Surface Electromyography for Use in the Occupational Setting; Expert Perspective. US Department of Health and Human Services, Public Health Services, National Institute for Occupational Health and Safety, 1992.

Thompson DA, Biedermaun HJ. Electromyographic power spectrum analysis of the paraspinal muscles. Long-term reliability. Spine. 1993;18:2310-2313.

Van Dieen JH, Toussaint HM, Thissen C, Van de Ven A. Spectral analysis of erector spinae EMG during intermittent isometric fatiguing exercise. Ergonomics. 1993;36:407-414.

APPENDIX A

CONSENT FORM

The investigator is conducting a research project that examines your calf muscles contraction to determine whether your two calf muscles fatigue in different ways. This research project will attempt to find reliable and valid fatigue indicators to be used in physical therapy practice. If you agree to participate in this study, you will be asked to *attend a screening interview* to determine whether you have any limitations that may interfere with your ability to perform the test

Once you are included in the research project after the screening interview, your leg lengths will be measured for the placement of the two electrodes that will record the muscle activity in your calf. After measuring and cleaning your skin with rubbing alcohol, two surface electrodes will be placed on the skin over the calf muscles. Another electrode will be placed on your kneecap. These electrodes will be connected to the electromyographic machine that collects information during your muscle contraction. You will be seated in a specialized chair with your knee straight and will be asked to push your foot downward against the stabilizing pedal for six seconds. You will be given a rest period and then will be asked to push your foot again for 66 seconds. While you will be pushing your foot downward against the pedal, muscle contraction data will be saved and processed using a computer software program

The risk of injury in this study is very low. You may experience muscle soreness in the calf muscles after the participation. Federal regulations require that all subjects be informed of the availability of medical treatment or financial compensation in the event of physical injury resulting from your participation in this research project. New York University will provide immediate, essential medical care for any physical injury resulting from your participation in this *research project* Neither financial compensation nor long-term medical treatment for such injuries will be provided. Information as to this policy and the availability of treatment can be obtained from the principal investigator or, alternatively, the New York University Office of Sponsored Programs (212) 998-2121.

You will not receive any direct benefit from participating in this experiment, except for your participation will contribute to the body of knowledge of physical therapy practice. You are free to withdraw from this experiment at any time. Your data and information will be given a random number, and your name will not appear in the results to maintain subject *confidentiality*.

AGREEMENT TO PARTICIPATE

I am aware that the investigator, Heonseock Cynn, is a New York University Master's degree student in the Department of Physical Therapy and that this experiment is part of his thesis requirement. An explanation of the procedures to be employed in the activity, for which I have volunteered, has been offered to me. I understand that all of the information which I provide will be held in the strictest of confidence, and that my name will not be identified. I know that I am flee to withdraw at any time, without penalty.

The above-cited elements were offered to me (check one)

In writing____ Orally ______

Date: __________

Name of Subject (Printed) ______________________________________

Signature of Subject ______________________________________

Signature of Experimenter ______________________________________

APPENDIX B

SCREENING INTERVIEW

Date: __________

Name: ________________________________ Sex: ________ Age: ______

Weight: ______Pounds Height: ________Feet _______Inches

Occupation: ____

Leg Dominance: Right _____ Left_____

1. Have you had any recent acute Illness or disease that would impair your ability to perform this test? Yes_____ No_____

   If "Yes", please describe: ____

2. Do you have any previous orthopedic or neurological problems that would impair your ability to perform this test? Yes_____ No_____

   If "Yes", please describe: ____

3. Do you participate in any sports activities? Yes____ No____

   If "Yes", please describe the amount of participation:

   Weekly. ________days per week

   Session length: ________hours ________minutes

   Participation length: ________years _______months

4. Are you taking any kind of medication? Yes _____ No _____

   If "Yes", please describe: ____