Memoirs of the Faculty of Engineering, Okayama University, Vol.30, No. 2, pp.15-20, March 1996

Estimation of Muscle Fatigue of Low Back upon the Muscle Stiffness

Hisao OKA* and Shiro FUJIWARA*

(Received January 25 , 1996)

SYNOPSIS

An estimation of muscle fatigue is very important study and many laboratory researchers had done actively in this field. The excellent measurement and analysis methods, however, have not established yet.

The aim of this study was to investigate the muscle fatigue of low back, caused by sitting on the vehicle seat for a long time. The muscle viscoelasticity and the EMG (Electromyogram) were measured. The authors proposed the objective muscle fatigue index that was obtained from the result of PCA (Principal Component Analysis) by using the measured variables. The objective muscle fatigue index suggests an adequate correlation with the subjective fatigue on the vehicle seat.

1. INTRODUCTION

Many people have experienced a muscle fatigue like a low back pain and shoulder pain in a daily life. A quantification of muscle fatigue is very important to suppress or ease it in the field of Medical Engineering and human science and so on. The muscle fatigue caused various changes on a living body, e.g. an increase of fatigue stuff in the blood. This paper deals with a change of muscle fatigue which is not chronic but transitory.

The purpose of this study is a estimation of the muscle fatigue caused by sitting on the vehicle seat for a long time with a change of muscle viscoelasticity. The biomechanical impedance is obtained from the response of the random vibration applied to the skin surface and then the muscle viscoelasticity is calculated. The subject sits on a standard seat and a worse seat, which is apt to make subjects occur the muscle fatigue on his back.

The final goal of this study is a propose of an objective muscle fatigue index based on the PCA (Principle Component Analysis), whose variables are muscle viscoelasticity and EMG (Electromyogram) between the standard and the worse seat.

2. BIOMECHANICAL IMPEDANCE AND VISCOELASTICITY OF MUSCLE

A diagram of measurement system of the biomechanical impedance[1] is shown in Fig. 1.

* Department of Electrical & Electronic Engineering

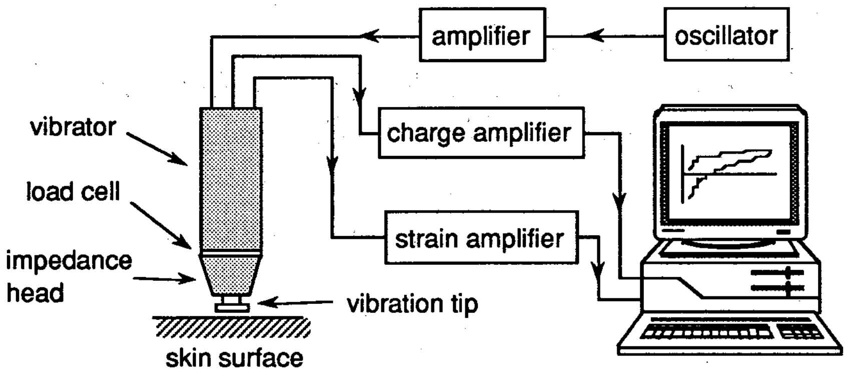

Fig.1 A diagram of measurement system of the biomechanical impedance.

The random vibration which is restricted from 30 to 1000 Hz is applied on a living body. An acceleration a(t) and a force f(t) response at driving point are detected by an impedance-head of measuring probe, and then they are taken into a personal computer (EPSON, PC-386S). The mechanical impedance is calculated by using the FFT (Fast Fourier Transform) of these signals as follows;

$$Z(f) = \frac{F(f)}{v(f)} = \frac{F(f)}{A(f)/j\omega} = j\omega\frac{F(f)}{A(f)} \quad \cdots (1)$$

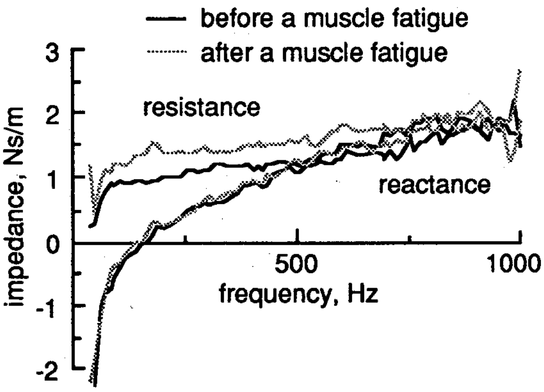

Fig. 2 Biomechanical impedance spectrum before / after a muscle fatigue.

Figure 2 shows a biomechanical impedance spectrum before / after a muscle fatigue, when the muscle become fatigued. To evaluate this spectrum change, the coefficient of shear elasticity μ_1 (N/m^2) and the coefficient of shear viscosity μ_2 (Ns/m^2) are introduced, which are calculated from the impedance spectrum by using a radiation impedance equation Z(f) proposed by Oestreicher[2,3].

$$Z = 6\pi a^2\sqrt{\frac{\rho\left(\sqrt{\mu_1^2+\omega^2\mu_2^2}+\mu_1\right)}{2}} + 6\pi a\mu_2 + j\omega\frac{2\pi a^3\rho}{3}$$
$$+ j6\pi a^2\sqrt{\frac{\rho\left(\sqrt{\mu_1^2+\omega^2\mu_2^2}-\mu_1\right)}{2}} + \frac{6\pi a\mu_1}{j\omega} \quad \cdots\cdots (2)$$

3. MEASUREMENT OF A MUSCLE FATIGUE ON A VEHICLE SEAT

3.1 Setting up a Vehicle Seat

An experienced vehicle seats are shown in Fig. 3. Fig. 3(a) shows "the standard seat" which we usually use in the vehicle. The seat includes four holes (ϕ 25 mm) to measure the muscle viscoelasticity of the low back. These holes don't influence the muscle fatigue. In the case of "the worse seat", shown in Fig. 3(b), a sponge rubber and "S" spring of lumbar part are removed. This seat forces the subject to sit with a stoop and makes him occur the muscle fatigue of his low back.

The lumbar inclinations of two seats are the same. The lumbar seat has an inclination of 23 degrees to the vertical line, whereas the vehicle seat is usually inclined by 25° .

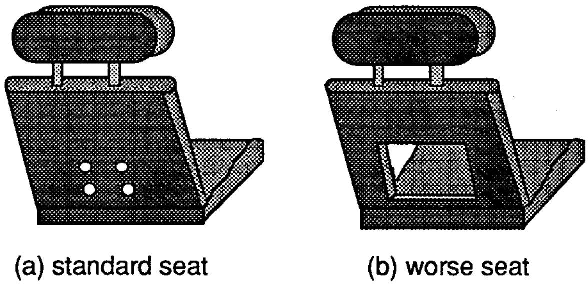

Fig. 3 Experienced vehicle seats.

3.2 Measurement of Muscle Viscoelasticity and EMG

When a man drives a car, he sits on a seat, grasps a steering wheel and looks ahead. In order to make a same driving situation in the experiment, the vehicle seat and steering wheel are arranged as same as the actual car. The subject grasps a steering wheel with his left hand and chases a mover, projected on the monitor, by a track ball with his right hand, as long as he sits.

Measuring points should be selected the parts which apt to occur a change of muscle stiffness. The four measuring points of viscoelasticity are each 40 mm away at the right and left side of the spinal column between the 3rd and the 4th lumbar vertebra, and between the 4th and the 5th lumbar vertebra as shown in Fig. 4. EMG is also measured to estimate a muscle fatigue. The EMG electrodes are pasted in each 1 channel at right and left side of the low back as shown in the figure, and the right leg is earthed.

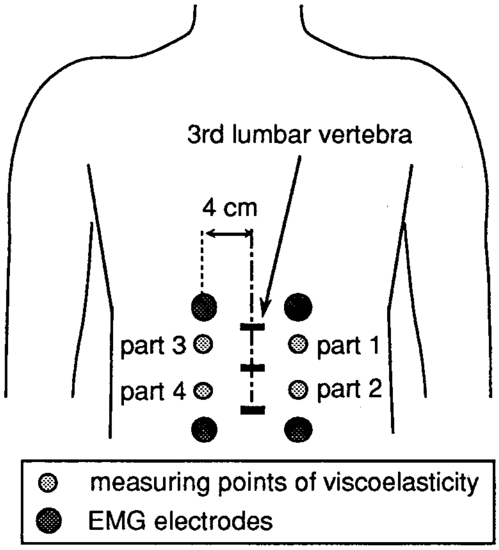

Fig. 4 Four measuring points of viscoelasticity and two channel EMG electrodes.

The measurement schedule of viscoelasticity and EMG is shown in Fig. 5. After a subject is seated, the viscoelasticity and EMG are measured every 30 minutes (1 set of measurement), and this set is practiced 7 times for 3 hours. The subjects are six men who are about 22 years old and usually drive a car, and the measurements are totally tried 13 times. The subject should state a subjective pain of his low back by classifying 6 grades from 0 (right after sitting) to 5 (a pain which he can't endure).

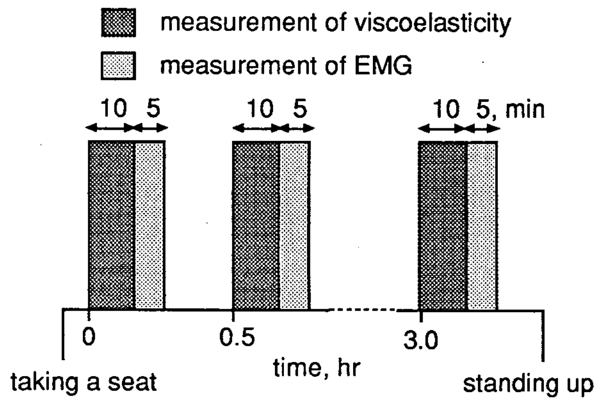

Fig. 5 Measurement schedule of viscoelasticity and EMG.

3.3 Experimental Results

The viscoelasticity is calculated from the biomechanical impedance spectrum by using the eqn. (1). The changes of elasticity and

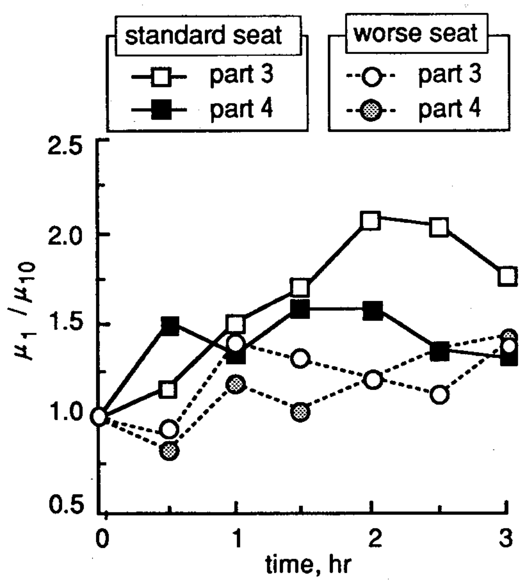

Fig. 6 Elasticity variation between the standard and the worse seat.

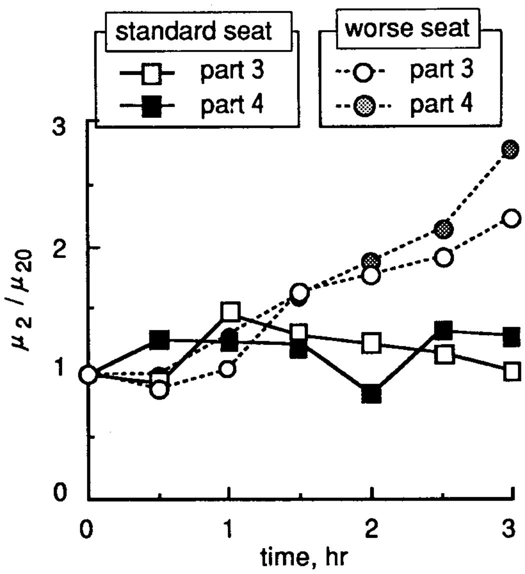

Fig. 7 Viscosity variation between the standard and the worse seat.

viscosity between the standard and worse seat are shown in Fig. 6 and Fig. 7. A vertical axis is normalized by the value at 0 hr (right after sitting).

The elasticity μ_1 increases similarly in both seats. In the case of worse seat, however, the elasticity of all parts decreases temporarily at 30 minutes after sitting. At the same time, the subject has complained of a low back pain. The same facts are found 8 times out of 13. As this is not found in the standard seat, μ_1 seems to relate to a early muscle fatigue.

On the other side, the difference between the both seats is found in the viscosity μ_2. In the worse seat, μ_2 increases monotonously , but in the standard seat, μ_2 almost never changes. According to the subjective degree of muscle fatigue, he has felt pains at his low back and buttocks after 30 minutes and the pain has increased with the passage of time. At 2 hours after sitting, he has felt a numbness in the femur. Hence not only the low back but also the buttocks and the femur are loaded owing to keeping the uncomfortable posture such a stoop for a long time. But he has hardly felt pains in the standard seat.

4. DISCUSSION

The elasticity μ_1 increases similarly between the both seats and the viscosity μ_2 shows the different tendency, Hence μ_1 corresponds to the change of muscle stiffness itself owing to sitting on the seat, and μ_2 corresponds to the change of muscle stiffness owing to keeping the worse posture for a long time. The authors have examined the relationship between the viscoelasticity and the EMG which are measured at the same time. When the muscle become fatigued, an amplitude of integrated EMG (IEMG) becomes generally larger and the median frequency of EMG spectrum (MNF) becomes lower[4~8]. The IEMG is an integrated value of the RMS (Root Mean Square) of EMG every 0.2 second, and the MNF is a frequency which divides the whole area of EMG spectrum into two equal areas. As the volume of electric discharge of EMG is not too sufficient only in the seat-sitting, the measurement of EMG is difficult. The method of electric discharge of EMG is shown in Fig. 8. In order to make the volume larger, the subject pulls the dynamometer with stretching his both arms, which is fixed to the wheel. The pulling force of dynamometer is 15kgf and it is about 10% of maximum pulling force of low back of adult man. The muscle fatigue is not influenced by the pulling of dynamometer.

The EMG spectrum in the case of worse seat is shown in Fig. 9. As the spectrum gradually becomes sharp and its amplitude becomes large, it appears that the muscle fatigue occurs. When the subject complains of a low back pain at 30 minutes after sitting, μ_1 decreases temporarily, however, the EMG doesn't change. Hence the muscle fatigue seems to be analyzed more in detail by the viscoelasticity than by the EMG.

The muscle fatigue is synthetically estimated by using PCA (Principle Component Analysis) with the measured variables. These variables are μ_1 and μ_2, MNF and IEMG. The result of PCA is shown in Fig. 10. As the cumulative proportion is 0.833 within the 2nd component, the 1st and 2nd component are under consideration. The figure shows that the 1st component expresses the change of muscle stiffness and the 2nd component expresses the objective fatigue. The straight lines in the figure are used for approximation. Next the authors construct a perpendicular to the line from each measurement point. We obtain the distance between the foot of the perpendicular from the starting point (right after sitting) and that from each measurement point. The distance means an objective muscle fatigue. The relation between the objective muscle fatigue and the subjective fatigue is shown in Fig. 11. In the worse seat, the objective muscle fatigue corresponds to the subjective fatigue and it appears that the muscle becomes fatigued. When the subjective fatigue is 1, the objective muscle fatigue takes a negative, because the muscle stiffness decreases at 30 minutes after sitting. In the standard seat, such a change is not found and the dispersion of the measurement points is narrow. Hence the muscle

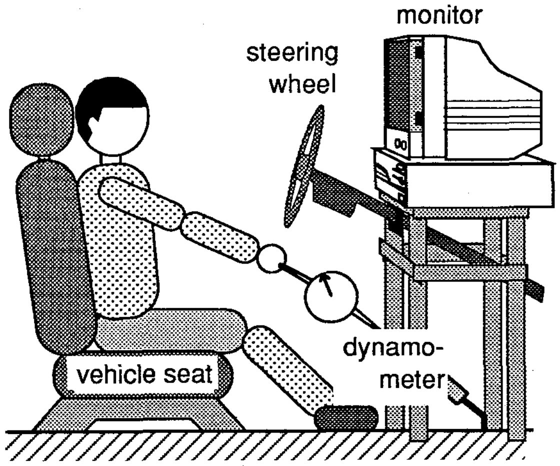

Fig. 8 Vehicle arrangement and EMG measurement.

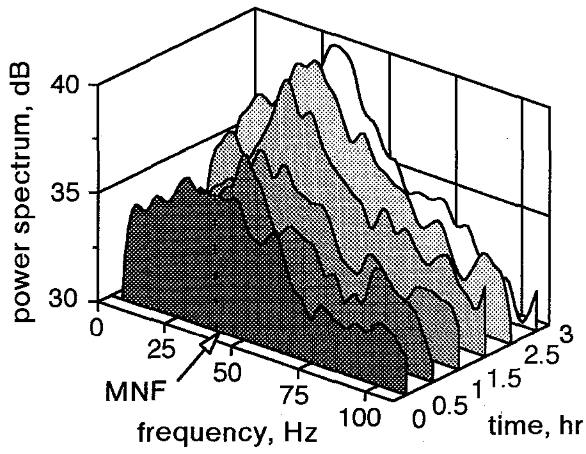

Fig. 9 EMG spectrum variation in the worse seat.

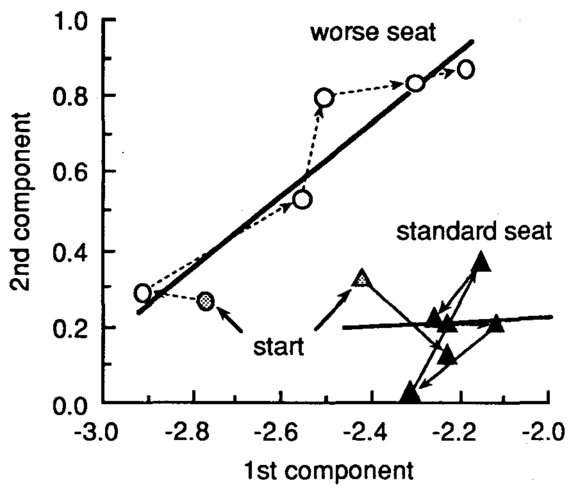

Fig. 10 PCA with variations of viscoelasticity and EMG between in the standard seat and in the worse seat.

is supposed to become less fatigued than in the worse seat.

5. CONCLUSIONS

In this paper, the biomechanical impedance of a low back is measured and the viscoelasticity is calculated from their spectra. The EMG is also measured. While the subject sits on the vehicle standard / worse seat for a long time, the muscle fatigue of low back is estimated based on them. The objective muscle fatigue is proposed, which is obtained from the PCA with the variations of μ_1, μ_2, MNF and IEMG. An adequate correlation between the subjective fatigue and the objective muscle fatigue is estimated from the results of measurements.

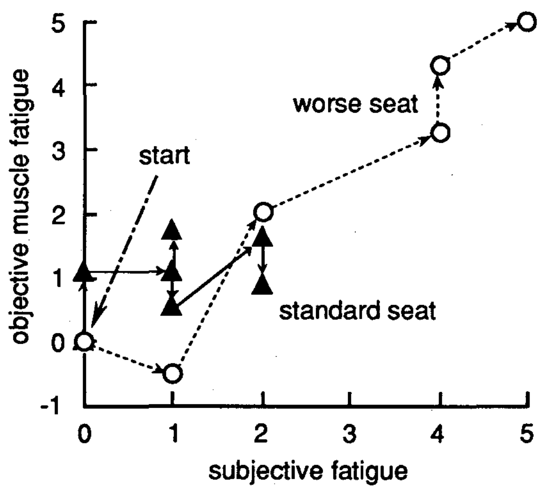

Fig. 11 Relation between the subjective fatigue and the objective muscle fatigue.

ACKNOWLEDGMENT

This research was supported financially in part by the Scientific Research Fund of the Japanese Ministry of Education (No. 06650470).

REFERENCES

(1) H. Oka, T. Yamamoto and Y. Okumura: Measuring Device of Biomechanical Impedance for Portable Use, Innov. Tech. Biol. Med., 8(1)(1987),1,11.

(2) H. L. Oestreicher: Field and Impedance of an Oscillating Sphere in a Viscoelastic Medium with an Application to Biophysics, J. Acoust. Soc. Am., 26(6) (1951),707,714.

(3) H. E. *von* Gierke, H. L. Oestreicher, E. K. Franke, H. O. Parrack and W. W. Wittern: Physics of Vibrations in Living Tissues, J. Appl. Physiol.,4(1952),886,900.

(4) S. Roy, C. J. Deluca and D. A. Casavant: Lumbar Muscle Fatigue and Chronic Lower Back pain, Spine, 14(9)(1988), 992,1001.

(5) R. Seroussi, M. H. Krag, P. Wilder and M. H. Pope: The Design and Use of a Microcomputerized Real-time Muscle Fatigue Monitor Based on The Medial Frequency Shift in the Electromyographic Signal, IEEE Transactions on Biomedical Engineering, 36(2)(1989), 284, 286.

(6) C. J. Deluca: Use of the Surface EMG Signal for Performance Evaluation of Back Muscles, Muscle & Nerve, 16(1993), 210, 216.

(7) M. Moffroid, S. Reid, S. M. Henry, L. D. Haugh, A. Ricamoto: Some Endurance Measures in Persons with Chronic Low Back Pain, Jospt, 20(2)(1994), 81, 87.

(8) R. Merletti and L. R. Lo Conte: Advances in Processing of Surface Myoelectric Signals: part 1, Med & Biol. Eng. & comput.,33(1995),362,372.