African Journal of Biotechnology Vol. 9(11), pp. 1690-1700, 15 March, 2010
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2010 Academic Journals

*Full Length Research Paper*

# Evaluation of human body comfortableness under vibrate condition by muscle oxygenation and surface electromyography (SEMG) parameter

**Xiaoling Li[1], Jun Hong[1]*, Fang Wang[2], Tong Wu[2] and Xiang Zhang[1]**

[1]School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, IL 710049, China.
[2]Institute of Industrial Design, Northwestern Polytechnical University, Xi’an, IL 710072, China.

Accepted 19 February, 2010

**To efficiently evaluate the influences on human body comfortableness under different vibrative condition, the paper comprehensively applied the surface electromyography (SEMG) and near infrared spectroscopy (NIRS) technology and obtained the relationship between mean power frequency (MPF) and regional tissue oxygen saturation (rSO2) and acceleration, frequency, time and amplitude through experiments on the variations of human body SEMG and muscle oxygenation under vibrative condition; analyzed and compared rules of variations of partial electromyography of the biceps brachii muscle, erector spinae muscle, biceps femories and tissue blood oxygen saturation depending on the changes of vibration parameter. With the analysis of the subjective evaluation, the author proposed the evaluation methods of human body comfortableness under different vibrate condition by muscle oxygenation and SEMG parameter. The study, with a certain degree of universalized quality, not only provides a new referential ergonomic criterion for the man-machine interface design of important facilities like tank and aircrafts, but can also be applied in the design evaluation of transportation vehicles and the evaluation of comfortableness of work environment.**

**Key words:** Vibration, comfortableness, biology, surface electromyography (SEMG), near infrared spectroscopy (NIRS), evaluation.

## INTRODUCTION

The security, reliability and humanized design of man-machine operation interface of the human-machine-environment system is a very significant part of ergonomic evaluation, particularly under special conditions, such as vibration which produces critical impact on the safety of the operator.

The key factors for the evaluation of the impact of vibration on human body includes frequency, amplitude, acceleration, time and the way of human body under vibrative condition. Studies show that human body are liable to resonance, which will directly impact the muscular system, the respiratory system, the circulatory system, the vegetative nervous system, the sensory system and make people feel uncomfortable thus, negatively impact the operation safety (Pan, 2004; Li et al., 2009). This does not mean that high-frequency vibration does not harm the human body. It depends on the acceleration. The faster the accele-ration, the more negative impact it has on human body. That is because fast acceleration creates wide amplitude, if human body stays under vibrative condition of high frequency and high acceleration for a long period of time, muscles will be in a lasting strained situation which will produce huge load whose accumulation will cause changes of physical features of the muscles, presenting in the way of reducing excitability, conductibility and contractibility, the weakening of strechability and flexibility of muscles as well as the failure of generating enough needed energy-which is called muscle tiredness (Wood and Bigland-Ritchie, 1984). When tired, the metabolizing outgrowth increases and the conducting speed of muscle fiber decreases. In the blood supply to fingers and toes as well as obstacles of nerve ending sense shown in the way of nerve ending convulsion and abnormity of brain blood flow graph (Giese, 1984); in the muscle tissue, there will be counterbalanced oxygen deficiency which is reflected

---

*Corresponding author. E-mail: xjtulxl@163.com.

**Table 1.** Comfort index of human rating and the car with different acceleration (ISO2631-1997).

| $a_w$ mm/s$^{-2}$ | <0.315 | 0.315~0.63 | 0.5~1.0 | 0.8~1.6 | 1.25~2.5 | >2.0 |
|---|---|---|---|---|---|---|
| **Human rating** | No discomfort | Somewhat uncomfortable | A little uncomfortable | uncomfortable | Very uncomfortable | Extremely uncomfortable |
| **Comfort index of driving (C)** | 1.0 | 0.8 | 0.6 | 0.4 | 0.2 | 0.0 |

in the way of oxygen deficiency of some tissue while its oxygen concentration in blood increases (Mcgill et al., 2000; Laishun, 1993). The technology of surface electromyography (SEMG) has offered practical technique method to measure the intrinsic load of muscle, the stimulus-response condition of muscle and to predict muscle strain (Luttmann et al., 2000). Because SEMG technology is able to overcome the problems of human subjective mental evaluation and quantitatively measure work load and muscle function situation and there is significant correlations between index figure and subjective feeling of tiredness (Dedering et al., 1999; Dedering et al., 2002; Guerrero et al., 2010), SEMG technology has therefore, been widely applied in the field of sports medicine, rehabilitation medicine, ergonomics and biomechanics (Jeffery and Glenn, 1998; Xitian et al., 2006).

In recent years, many researchers analyzed human fatigue from the aspect of metabolism. Study results have shown that there are two main reasons for muscle strain: one is the exhaustion of adenosine triphosphate (ATP) or creatine phosphate (CP) which is the major energy for muscle constriction; another is the accumulation of metabolite (Guyton, 1980). All of the above two reasons are directly related to the blood supply of muscle. Oxygen is a very important substance of blood. Therefore, oxygen deficiency is likely to be a major cause of muscle strain. So oxygen uptake and lactic acid correlations, as referential index, may reflect the metabolism of oxygen level of the whole body (Mower et al., 1997; Miller et al., 1979). Near infrared spectroscopy (NIRS) technology provided a practical technique for quantitatively measuring the demand and supply situation of oxygen in muscles. It is a non-harm measurement that uses the perfect penetrating ability of near infrared to tissue, based on the biochemical information of muscle tissue carried by the infrared which has gone through all sorts of absorption in the muscle, with the laser bougie connected to the soft tissue of skeletal muscle to record the variations of real time oxygenation of the blood flow (Yichao et al., 2004). In medical field, regional tissue oxygen saturation ($rSO_2$) is usually used to reflect the oxygenation of muscle tissue. It is defined as the ratio between the concentration of oxyhaemoglobin ($HbO_2$) and the concentration of [$HbO_2$] and [Hb] (hemoglobin), which is:

$$\mathrm{rSO_2} = \frac{[\mathrm{HbO_2}]}{[\mathrm{HbO_2}]+[\mathrm{Hb}]}\times 100\% = \frac{[\mathrm{HbO_2}]}{[\mathrm{tHb}]}\times 100\% \quad (1)$$

Among which [$HbO_2$] and [Hb] present the concentration of $HbO_2$ and Hb respectively, the unit is written as mol/L. Because the different absorption coefficient of [$HbO_2$] and [Hb] to light of different wave length, through measuring the attenuation of light in the process of transportation in human body tissue, $rSO_2$ of the muscle tissue can be obtained. Therefore, the oxygenation of muscle tissue can be timely and accurately reflected and the demand and supply situation of oxygen in muscle tissue can be obtained.

In the traditional measure of muscle strain level, electromyography parameter is usually considered, but it is considerably limited due to the difficulty in consecutive real time collection. With the technology of NIRS, the supervision and measure of muscle oxygen in dynamic situation can be realized. Nowadays, the study about muscle fatigue mostly concentrate on the measurement of electromyography signal and muscle oxygen level of human body in dynamic situation, such as the study of an athlete when doing a group of strenuous movements (Kazumi et al., 1999). As for the studies about muscle oxygenation's reflection of muscle movements, only one was found (Wang et al., 1999). At present, the study that integrates muscle oxygenation and electromyography signal into the research of muscle fatigue cannot be found, which deserves further probing.

## MATERIALS AND METHODS

### Subjects

In this study, 8 subjects were chosen, among whom 5 were male and 3 female, with age range of 20 to 40 years old. The major purpose is to measure the SEMG, $rSO_2$ and rating of perceived exertion (RPE) of the biceps brachii muscle, erector spinae muscle and biceps femories under vibrative condition. Additionally, the oxygen level of brain tissue will also be measured. All of the subjects are healthy with normal physical development and with neither history of muscle and skeletal disease nor spondyle abnormality.

### Experimental design

The study adopted the SA30-S802/ST electromagnetic vibration laboratory furniture produced by UD Company in USA and the ME6000 surface electromyography test system produced by Mega Company in Finland and the TSAH-100 near infrared non-invasively human tissue oxygenation monitoring apparatus and modeled an experimental driving environment on the vibration test bed. According to the ISO2631-1: 1997 (E) (Table 1) evaluation on

**Table 2.** Subjective rating score.

| Score | Fatigue level | Description |
|---|---|---|
| 1 - 2 | Not tired | No strange feeling. Physically and mentally comfortable. |
| 3 - 4 | A bit tired | A bit physical discomfort. Failed in concentrating in mind. |
| 5 - 6 | Tired | Partial fever. Nausea. Fidget. |
| 7 - 8 | Very tired | Dizzy. Partial numbing with breathing problem. |
| 9 – 10 | Extremely tired | Numbing. Fast heartbeat with serious breathing problem. |

human endurance of full body vibration**,** the study adopted the testing method of acceleration swept frequency (5 -30 HZ).

The common acceleration due to gravity in vibration is written as g ($9.8ms^{-2}$), for example, 10 g means that the shock which equals 10 g is endurable. So through the transformation of the weighted acceleration in ISO2631-1: 1997, the acceleration in the vibration experiment was categorized into five levels: 0.03, 0.06, 0.1, 0.15 and 0.20 g and they are all power from vertical direction.

### Experimental procedure

According to ISO2631-1: 1997 standards, the human body can be divided into different positions (stand, sit and lying). These were measured. But this article mainly researches the cockpit environment during vibration conditions, so we chose the site of the concentration of power under the state of driving. Thus, the biceps brachii muscle, erector spinae muscle and biceps femories were measured (Figure 1).

### Subjective rating of comfortableness

Due to the fact that subjective feelings is a comprehensive reflection of physical (muscle), mental (mental) and sensory fatigue, subjective scores obtained from experiment could reflect the comfort of driving. The subjective rating of comfortableness was divided into 5 levels, with ratings ranging from 1 to 10. Modifications were done according to the feelings of testees. The representative meanings of the ratings are shown in Table. 2.

There was one frequency sweep (5-30 Hz) every 5 min and each level of vibration lasts 20 min. Meanwhile, data collection was conducted and subjective evaluation scores were collected. Based on the corresponding relationship of time point and frequency, the variations of muscle oxygenation and the subjective feelings of the testees during the process from low frequency to high frequency were obtained.

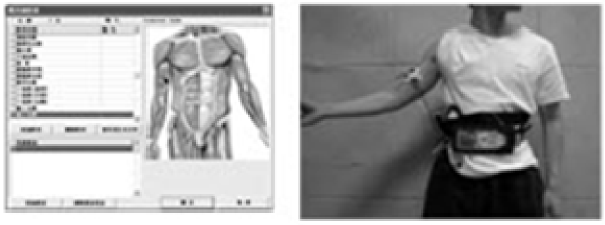
## RESULTS

### Electromyography

The common method is non-invasive measure which is to get electromyography signal through bipolar electrode lead and transform it into the frequency feature parameters that can reflect the variations of conducting speed, thus, reflect the fatigue level of muscle. These feature parameters were obtained mainly from the time domain analysis and frequency domain analysis.

Frequency domain analysis focuses on the fast Fourier transform of SEMG signal to get its frequency spectrum

(a) Experiment facilities

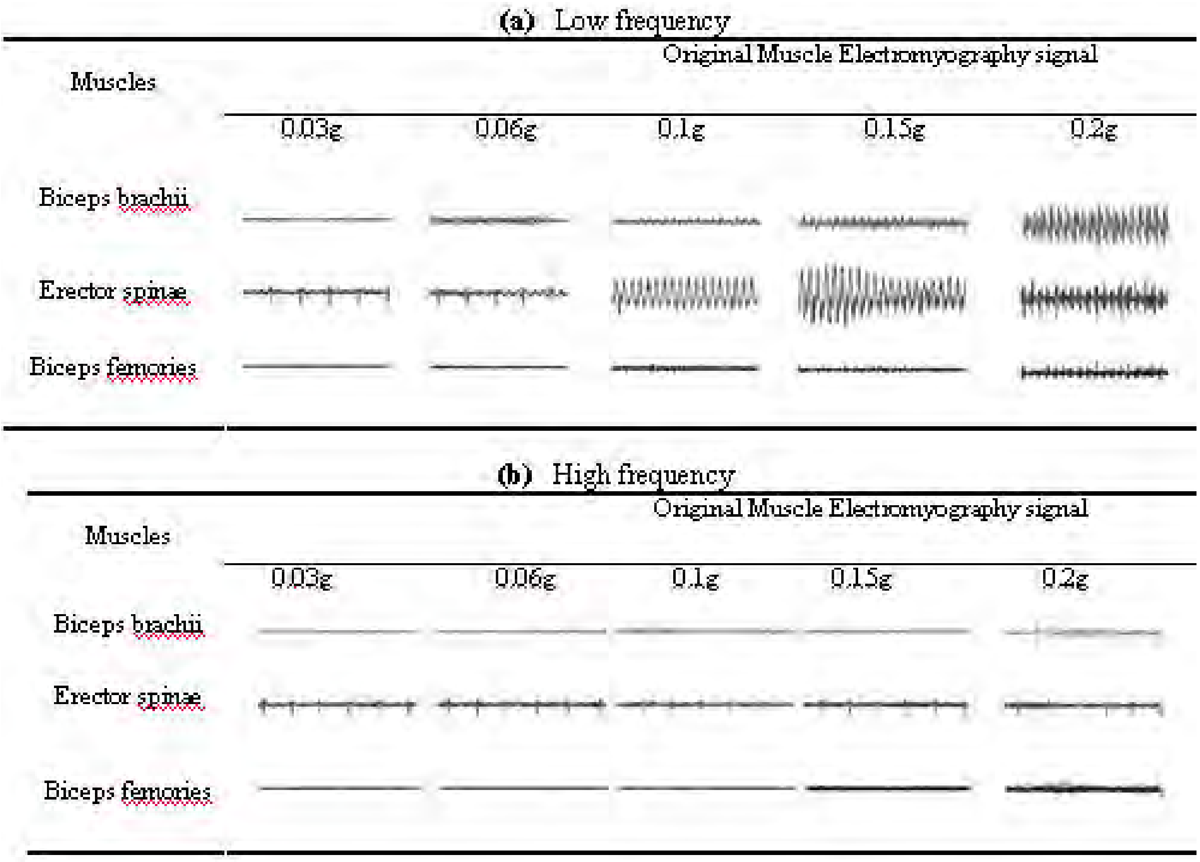


(b) Experimental site selection

(c) $rSO_2$ measured

**Figure 1.** Experiment process and facilities.

**Table 3.** The primitive electromyography signal with different acceleration.



(a) Low frequency

| Muscles | Original Muscle Electromyography signal | | | | |
|---|---|---|---|---|---|
| | 0.03g | 0.06g | 0.1g | 0.15g | 0.2g |
| Biceps brachii | | | | | |
| Erector spinae | | | | | |
| Biceps femories | | | | | |

(b) High frequency

| Muscles | Original Muscle Electromyography signal | | | | |
|---|---|---|---|---|---|
| | 0.03g | 0.06g | 0.1g | 0.15g | 0.2g |
| Biceps brachii | | | | | |
| Erector spinae | | | | | |
| Biceps femories | | | | | |

or power spectrum. The frequency spectrum movement of the power spectrum can be used as the experimental indicator of conducting speed of muscle fiber. So it is the reliable measuring parameter of muscle fatigue level. Electromyography frequency spectrum (EFS) and mean power frequency (MPF) can clearly indicate the movement of frequency spectrum. Because the variations of frequency spectrum under low workload condition bears the feature of high sensitivity and this study mainly focuses on the passive muscle fatigue level under vibarative condition in which there is no obvious major movement and is solely caused by human body vibration with long time of workload accumulation; the study therefore, adopts the method of frequency domain analysis (Li, 2006).

### EFS

When human body is incented by vibration in a certain period of time, there is a series of primitive muscle electromyography signal which changes with the variation of acceleration and frequency. The experiment shows that the higher the acceleration, the larger the electromyography. Under the same acceleration, the electromyography is larger in low frequency than that in high frequency, as shown in Table 3.

From the results (Table 3), it can be demonstrated by all types of electromyography frequency spectrum at different acceleration. Figure 2 is the comparison of the electromyography frequency spectrum of one subject in the initial stage and that with the acceleration from 0.03 to 0.2 g. It can be seen that with increase of acceleration, the whole frequency spectrum has the tendency of moving leftward. In Figure 2, pass 1, 2 and 3 presents for the biceps brachii muscle, erector spinae muscle and biceps femories, respectively. This also indicates that the fatigue level of different part of muscle is more and more obvious.

### MPF

The following is the cubic interpolation analysis on MPF data of the biceps brachii muscle, erector spinae muscle and biceps femories of subjects through Matlab. The result is shown in Figure 3. It shows that with the increase of speed, MPF of all the muscles increases with high acceleration. The smaller the MPF, the more tired the muscles are. When the biceps brachii muscle is under low frequency stage (10 and 20 min) and the acceleration

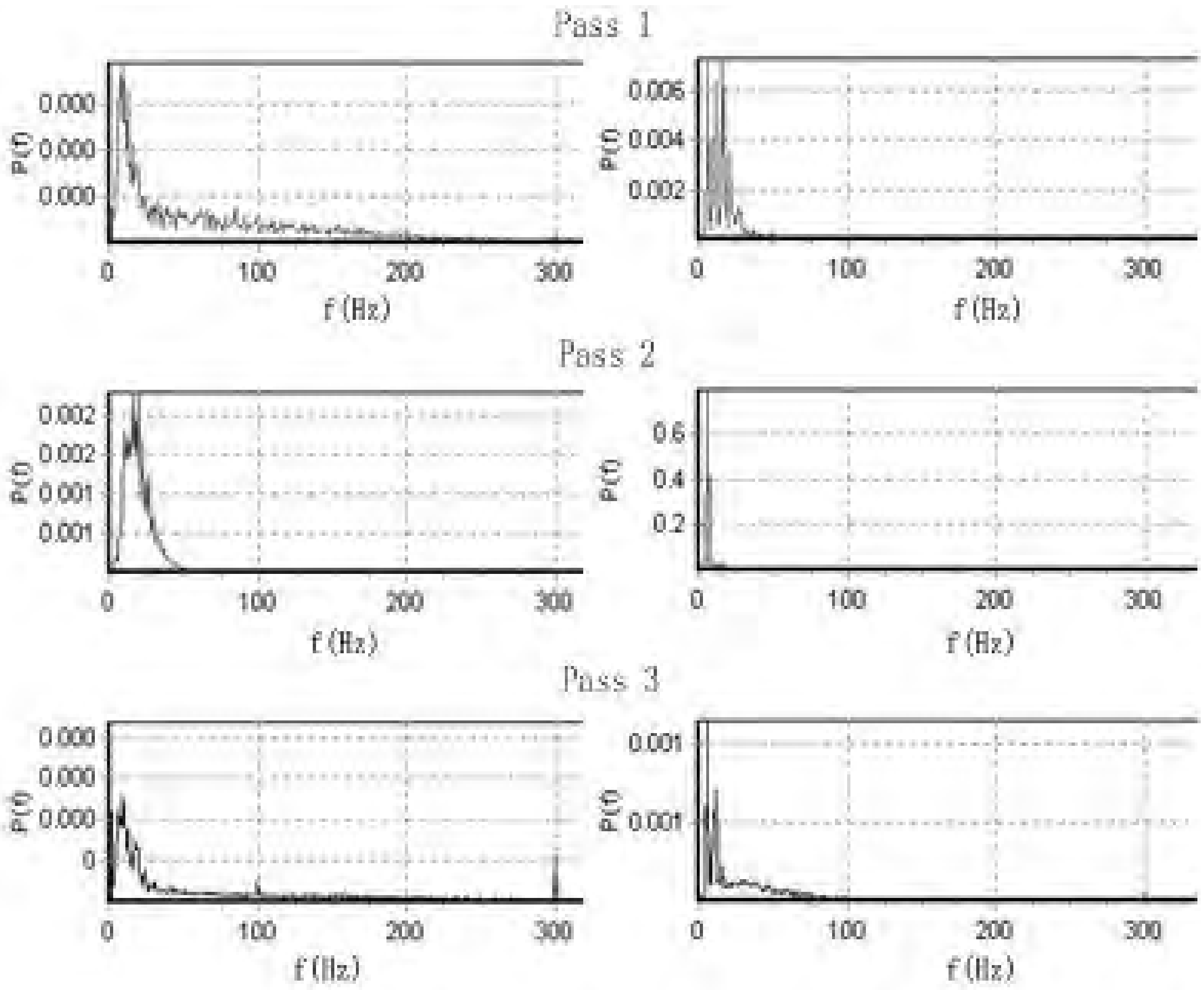
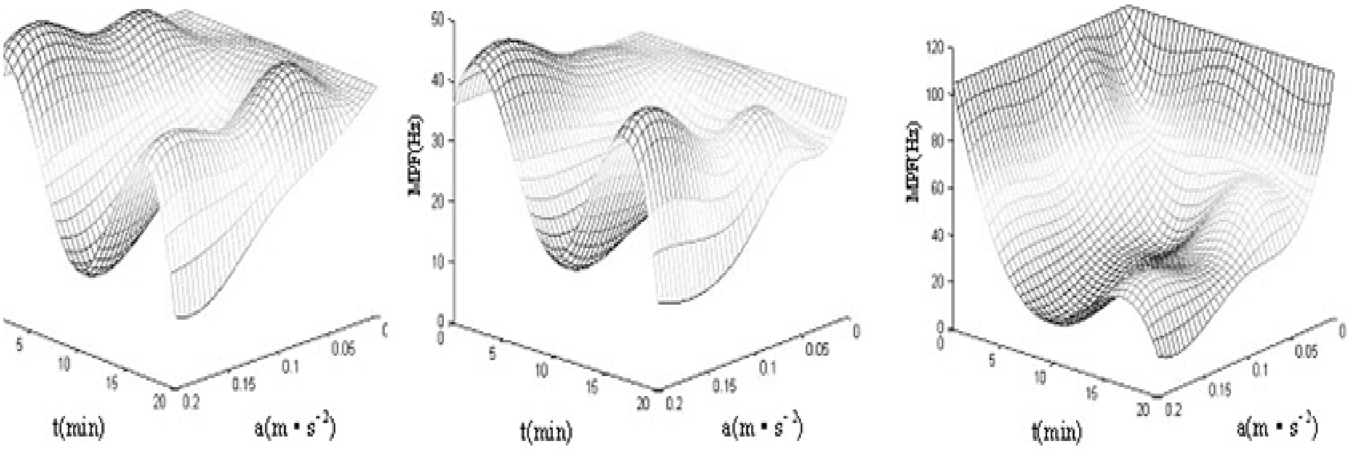


**Figure 2.** Comparison of the EFS.



(a) Biceps brachii (b) Erector spinae (c) Biceps femories

**Figure 3.** Relationship of partial muscle MPF with acceleration, frequency and time.

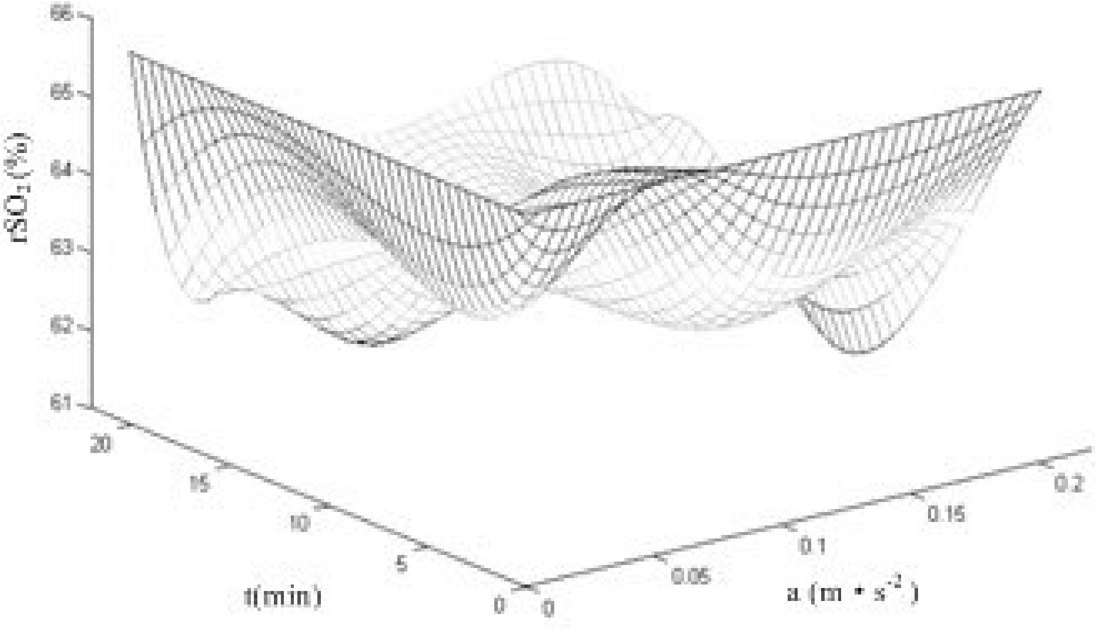


**Figure 4.** Variation of brain tissue frequency depending on acceleration.

is 0.1 and 0.15 g, the fatigue is obvious. When the acceleration on erector spinae muscle reaches 0.03 and 0.06 g, the fatigue of muscle is very obvious. Different from the above two muscles, biceps femories start level of fatigue was much lower than that of the other two muscles, which demonstrates that recovering ability is much weaker than the other two muscles.

Through the contrastive analysis of the three graphs, with the increase of acceleration, the variation of muscle MPF were obviously stronger. The MPF of all muscles reaches the lowest level under low frequency (10 and 20 min), which shows that humans are prone to tiredness in low frequency. Under the high frequency (5 and 15 min), the muscle MPF reaches its highest level, which shows that the muscles recovered themselves and the recovering level surpassed the fatigue level caused by time accumulation.

## Near-infrared spectrum

### Brain tissue

The variation of the average of the brain tissue rSO$_2$ of the 8 subjects, are shown in Figure 4. It can be seen that acceleration produced great impact on the fatigue level of brain tissue. The bigger the acceleration, the smaller the brain tissue rSO$_2$. When the acceleration increases from 0 to 0.03 g, rSO$_2$ decrease reaches it peak, which demonstrates that brain hypoxia level increased. The other influential factor is the change of frequency. Brain tissue rSO$_2$ decreases at the fastest speed at the frequency of 0-5 Hz and reaches its lowest level between 5 and 10 Hz.

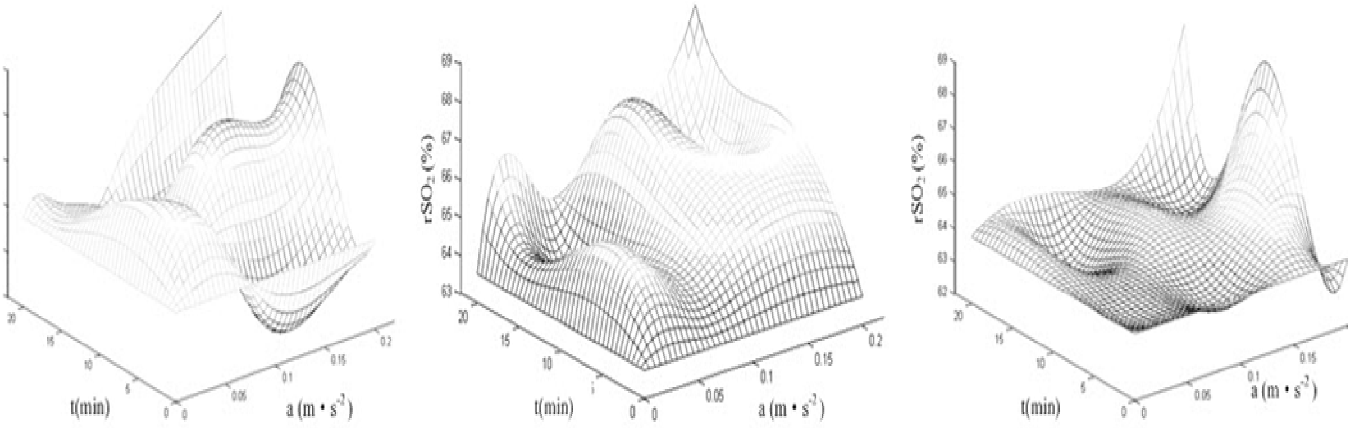
### Muscle tissue

The following is the cubic interpolation analysis on the rSO$_2$ of the biceps brachii muscle, erector spinae muscle and biceps femories through Matlab as shown in Figure 5.

It can be seen that with the increase of acceleration, the oscillation tendency became acute and the greater the acceleration, the higher the level of rSO$_2$, presented by the increase of rSO2; meanwhile the fatigue level increased accordingly. Acceleration produces a very big impact on the erector spinae muscle, when the acceleration was between 0.06 and 0.10 g, tiredness was obvious. The reaction of the biceps brachii muscle to frequency was also obvious, its rSO$_2$ at low frequency (10 and 20 min) was higher, vice versa and its highest level appeared between 5 and 10 Hz, which demonstrated that frequency between 5 and 10 Hz may produce a great impact on the biceps brachii muscle. Different from the above two blocks of muscle, biceps femories reflected obvious fatigue condition in the co-effect of high acceleration and low frequency. When acceleration is faster than 0.15 g, rSO$_2$ increases obviously. The increase level is higher in low frequency than that in high frequency. This indicated that for the biceps femories, with the acceleration increasing, its fatigue level in low frequency is obviously higher than that in high frequency.

## Subjective rating of comfortableness

Rating of perceived exertion (RPE) reflects the spiritual fatigue condition. In the real life driving situation, spiritual fatigue causes the main impact on human's driving



(a) Biceps brachii (b) Erector spinae (c) Biceps femories

**Figure 5.** Relationship of partial muscle $rSO_2$ with acceleration, frequency and time.

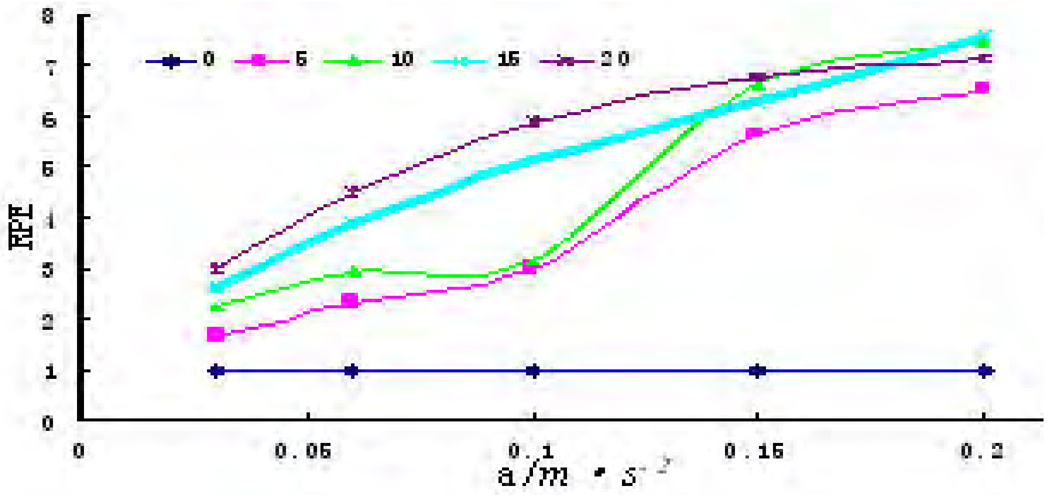


**Figure 6.** RPE with different acceleration.

behavior. Therefore, it is necessary to make specialized analysis on subjective rating.

From Figures 6, 7 and 8, it can be seen that the subjective rating curves interveined when the acceleration was over 0.15, which demonstrated the subjective rating on fatigue reached at high level after this point.

## DISCUSSION

In order to find the variation rules of human body comfortableness to vibration from muscle electromyography and muscle oxygenation data, a comparative study on every block of muscle was conducted as shown in Figures 9 - 14.

From the comparison, variation of tissue blood oxygen and electromyography signal MPF have linear negative relationship. This result further demonstrated that muscle fatigue under vibrative condition was caused by human's overcoming acceleration and there was no obvious initiative movement but all was caused by the passive vibration of human body. Particularly, under low frequency with high acceleration, if vibration amplitude of some parts is too strong, it will increase the heart sendout and accelerate blood circulation. It is reflected in the way of upward tendency of muscle oxygen in all tissues but brain oxygen; this is actually the human body compensatory hypoxia caused by body tissue hypoxia (Jin and Wang, 2005; Chen et al., 2009). Yet the nervous system, especially the pallium is very sensitive to hypoxia. With the time passing by, metabolism obstacles may happen if the body failed in compensating and therefore, making the pallium undergo serious nutrition metabolic obstacle. Thus, symptoms like nausea, vomiting,

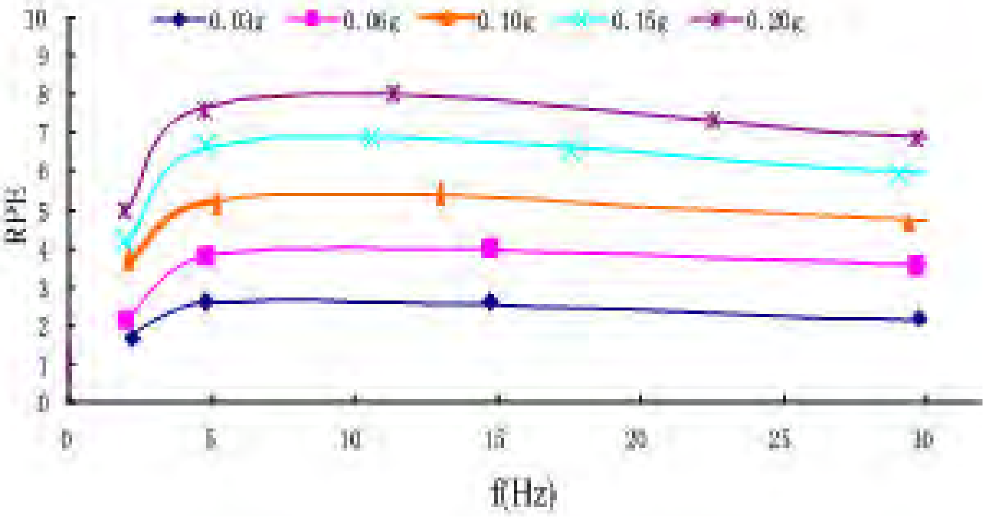


**Figure 7.** RPE with different frequency.

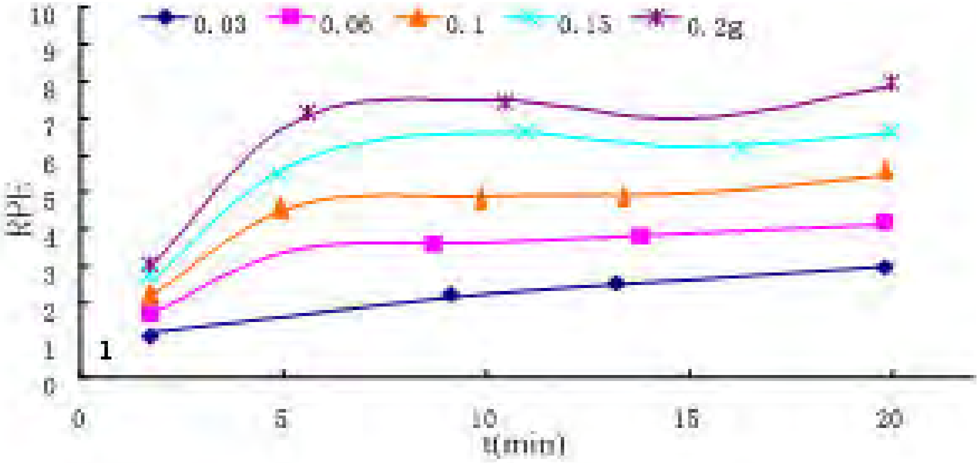


**Figure 8.** RPE with different time.

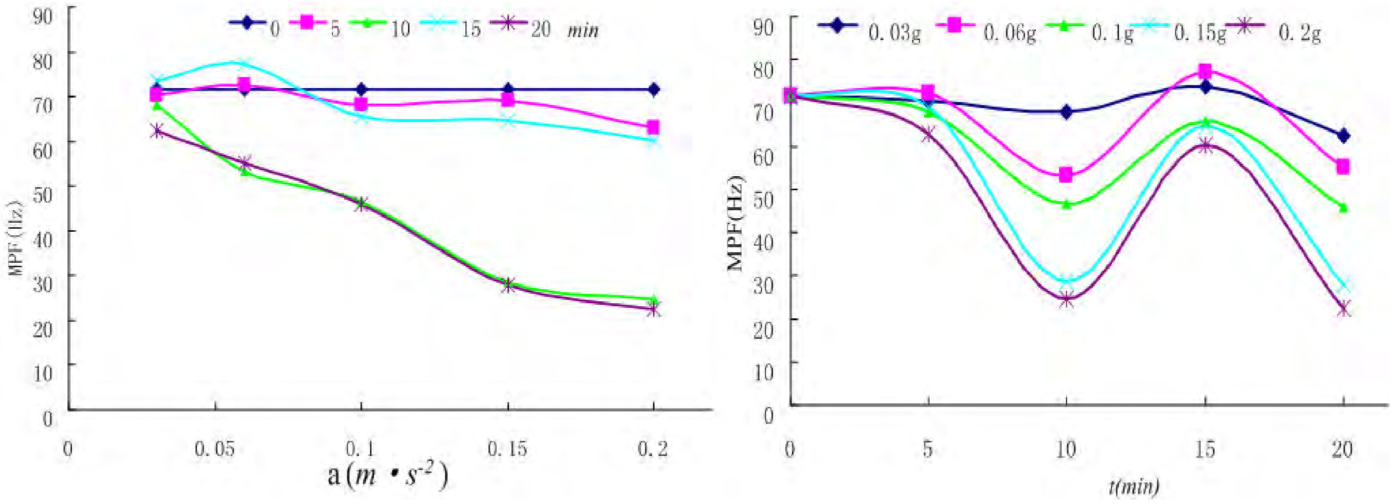


**Figure 9.** MPF tendency of the biceps brachii muscle with different acceleration and time. (a) MPF tendency with different acceleration; (b) MPF tendency with different time.

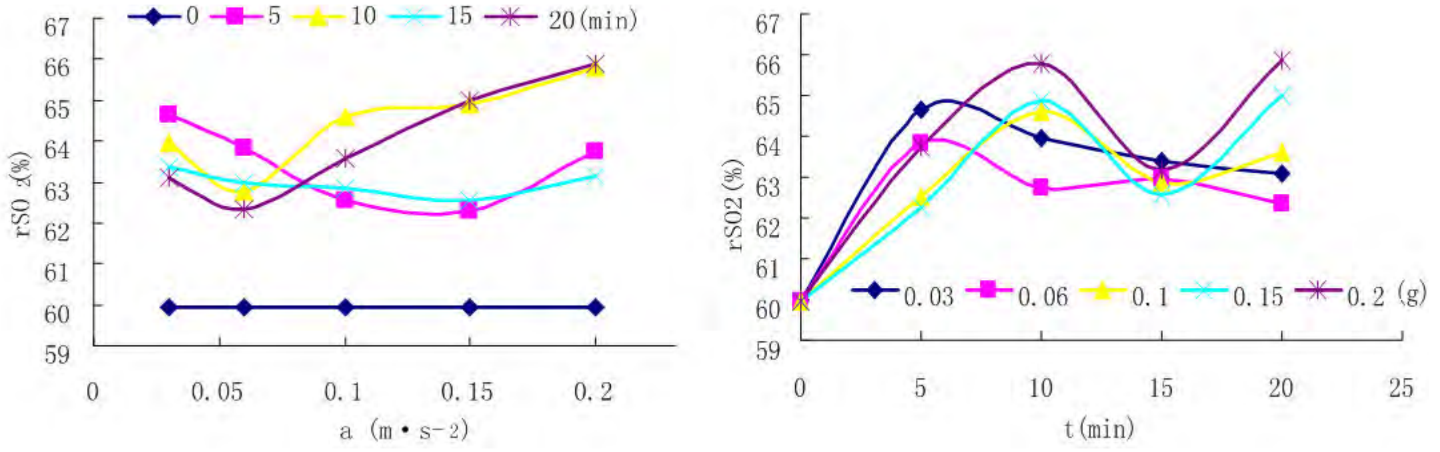


**Figure 10.** $rSO_2$ variation of the biceps brachii muscle with different acceleration and time. (a) $rSO_2$ variation with different acceleration; (b) $rSO_2$ variation with different time.

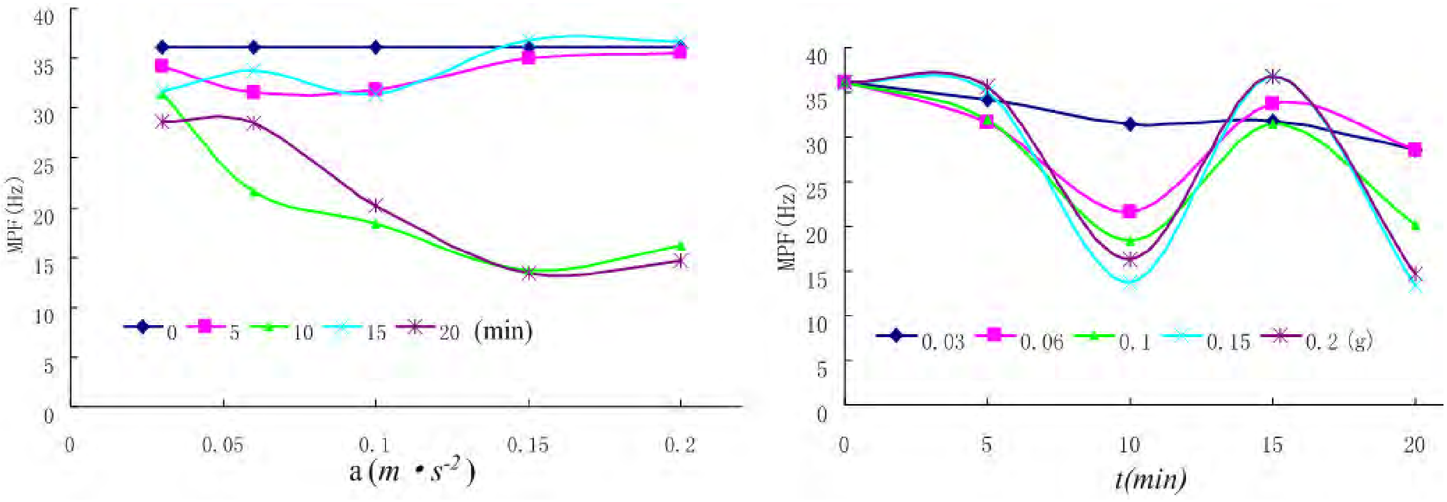


**Figure 11.** MPF tendency of erector spinae muscle with different acceleration and time. (a) MPF tendency with different acceleration; (b) MPF tendency with different time.

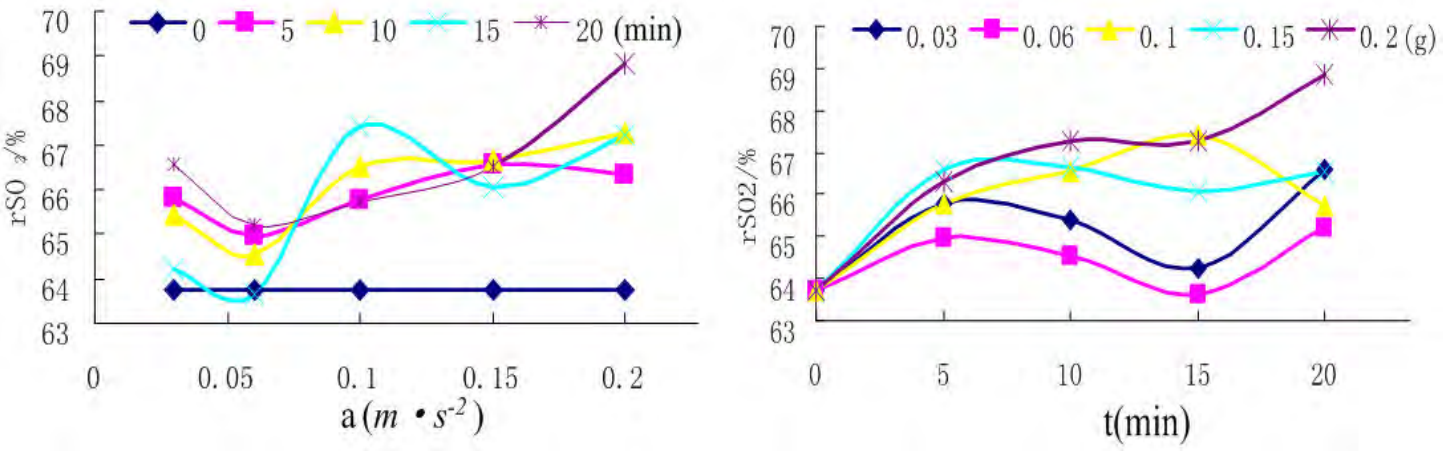


**Figure 12.** $rSO_2$ variation of the erector spinae muscle with different acceleration and time. (a) $rSO_2$ variation with different acceleration, (b) $rSO_2$ variation with different time.

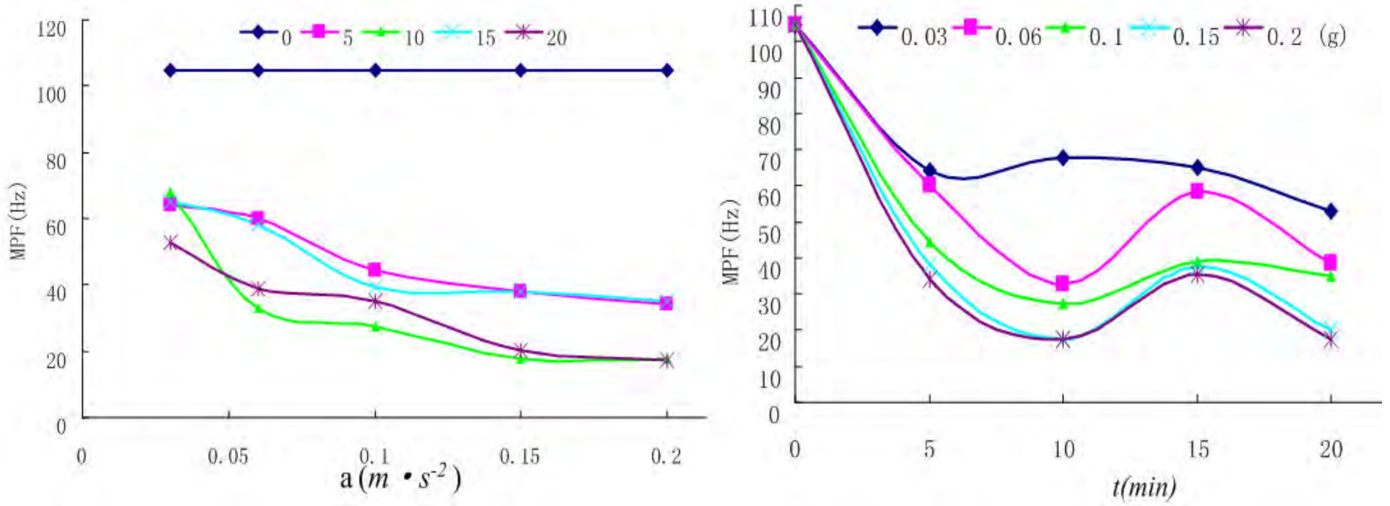


**Figure 13.** MPF tendency of biceps femories muscle with different acceleration and time. (a) MPF tendency with different acceleration, (b) MPF tendency with different time.

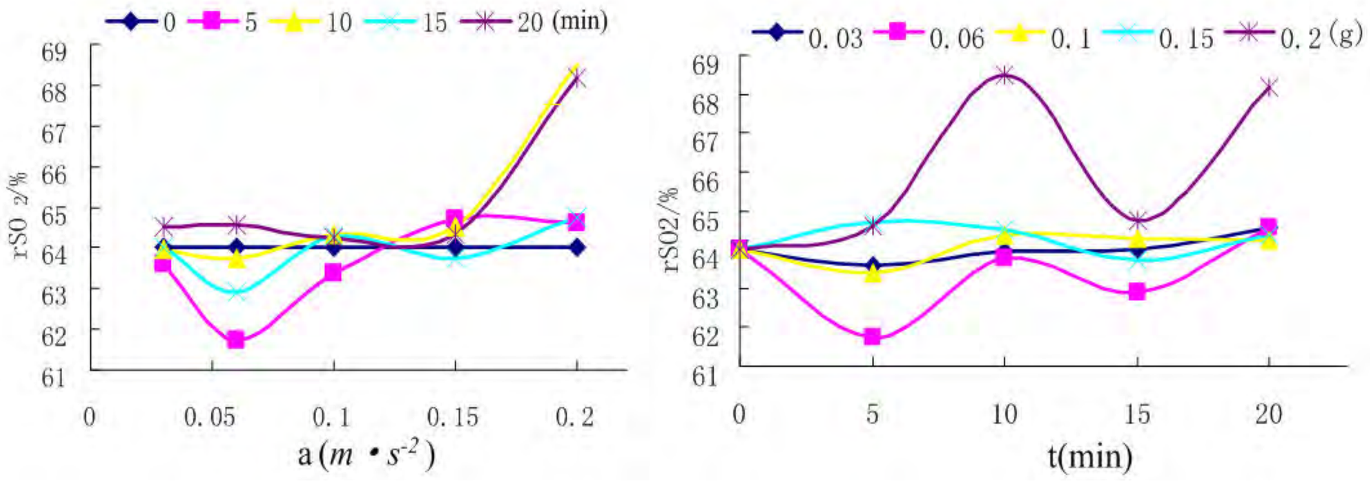


**Figure 14**. $rSO_2$ tendency of biceps femories muscle with different acceleration and time. (a) $rSO_2$ variation with different acceleration; (b) $rSO_2$ variation with different time.

headache, etc. will appear. Over breathing decreased the arterial pressure oxygen which weakens the stimulation of $CO_2$ to medulla oblongata chemoreceptor and limited the ventilation of lung so breathing problems were brought about. This result is consistent with the subjective feelings in the experiment and which is in accordance with the former simulation result (Li et al., 2008).

Acceleration have greater impact on the human body fatigue. With the increase of acceleration, all the human muscles are prone to fatigue. With acceleration of 1 g, the biceps brachii muscle reflects obvious fatigue and the fatigue level increases with the time accumulated. With the acceleration of 0.3 g the erector spinae muscle reflects obvious fatigue. Biceps femories is very sensitive to vibration and has poor recovering ability to fatigue. The ratio of muscle workload intensity (that is, the electromyography signal) to acceleration is positive and the muscle workload reaches its highest level with high acceleration and low frequency; meanwhile the muscle MPF gets to its lowest level. From the subjective ratings, the data collected from different groups are basically consistent with the above, which is, with the increase of acceleration, human body uncomfortableness also becomes more and more obvious.

## Conclusion

Evaluation on partial human body or entire human body comfortableness in dynamic environment with integration of partial electromyography signal and tissue blood oxygen saturation ($rSO_2$) is a brand new research field, home and abroad. The past studies on comfortableness in dynamic environment all depended on the scores derived from the subjective ratings of the testees and then propose the comfortableness evaluation principles according to the relationship of scores and environmental parameter. This paper inherited the past subjective ratings on comfortableness and established the experimental platform for examining the partial human body electromyography signal and tissue blood oxygen saturation, which objectively conducted the test of partial electromyography and tissue blood oxygen saturation. The paper took both subjective feelings and objective data as references in probing the rules for comfortableness evaluation. The result can be applied in the design evaluation of vehicles and work environment evaluation, among others. But because muscle electromyography signal and partial tissue blood oxygen saturation are related to large amount of bio-medical knowledge, the study on the increase of partial tissue blood oxygen caused by the tissue hypoxia in vibrative environment needs further study from the aspect of a wider and deeper pathology study, even from the aspect of micro human body cell.

## ACKNOWLEDGEMENT

The project is supported by Natural Science Basic Research Plan in Shaanxi Province of China (Program No.2009JM7001)

### REFERENCES

Chen X, Chen Y, Li S, Chen Y-G, Lan J, Liu L-P (2009). Free radical scavenging of Ganoderma lucidum polysaccharides and its effect on antioxidant enzymes and immunity activities in cervical carcinoma rats. Carbohydrate Polymers, 77: 389-393.

Dedering U, Nmeth G, Harms-Ringdahl K (1999). Correlation between electromyographic spectral changes and subjective assessment of lumbar muscle fatigue in subjects without pain from the lower back. [J]. Clin. Biomech. 14(2): 103-111.

Dedering U, Oddsson L, Harms-Ringdahl K, Gunnar N (2002). Electromyography and ratings of lumbar muscle fatigue using a four level staircase protocol [J]. Clinical Biomechanics, 17(3):171-176.

Giese AC (1984). SystolicCell physiology. BeiJing: China Science Press, p. 506.

Guerrero S, Teijón C, Muñiz E, Teijón JM, Blanco MD (2010). Characterization and in vivo evaluation of ketotifen-loaded chitosan microspheres. Carbohydrate Polymers, 79: 1006-1013

Guyton AC (1980). Nerve and muscle. Basic human physiology. LanZHou: Gansu People's Press, pp. 110-111.

International Standard 2631-1 (1997). Mechanical vibration and shock evaluation of human exposure to whole body vibration [S], Edition-1985.

Jeffery RC, Glenn SK (1998). Introduction to surface electromyography[M]. An Aspan Publication.

Jin H, Wang J (2005). Pathophysiology. BeiJing: People's Medical Press.

Laishun X (1993). Disease Caused by Partial Vibration and Its Treatment. Chin. J. Ind. Med. p. 32.

Li X, Zhang E, Lu C (2008). Driving Comfort Simulation Based on Human Biomechanics Model Under Vibration [J]. J. Xi′an Jiaotoang University, 42(5): 556-560 (in Chinese).

Li X, Zhang H, Xu H (2009). Analysis of chemical components of shiitake polysaccharides and its anti-fatigue effect under vibration. Int. J. Biol. Macromolecules, 45(4): 377-380.

Luttmann A, Jgger M, Laurig W (2000). Electromyography induction of muscular fatigue in occupational field studies [J]. Int. J. Ind. Ergon. 25: 645-660.

Masuda K, Masuda T, Sadoyama T, Inaki M, Katsuta S (1999). Changes in Surface EMG Parameters during Static and Dynamic Fatiguing Contractions [J]. Electromyography and Kinesiology, 9:39-46.

Mcgill SM, Hughson RL, Parks K (2000). Lumbar erector spinae oxygenation during prolonged contractions: Implications for prolonged work. Ergonomics [J], 43: 486-493.

Miller WL, Belardinelle L, Bacchus A, Foley, DH Rubio R, and Berne RM (1979). Canine myocardial adenosine and lactate production, oxygen consumption, and coronary blood flow during stellate ganglion stimulation[J]. Circ. Res. 45: 708-718.

Mower WR , Sachs C, Nicklin E, Baraff L (1997). Pulse oximetry as a fifth pediatric vial sigh [J]. Pediatrics, 99(5): 681.

Pan L (2004). Dynamic Modeling and Simulation of Vehicle Ride Comfort Based on Triaxial Vibrations of Person-Chair System. ZheJiang, ZheJiang University of Technology, p. 12.

Wang F, Li W, Lin F (1999). Non-invasive Test to Biology Tissue Oxygen Realized through the ***NIRS*** Technology [J]. Journal of Tsinghua University; Sci. Technol. 7: 16-19.

Wood J, Bigland-Ritchie B (1984). Changes in Muscle Contractile Prope-rties and Neural Control during Human Muscle Fatigue [J]. Muscle Nerve, 7: 691-699.

Xitian P, Chen F, Peng C (2006). Methods Applied to Muscle Fatigue Assessment Using Surface Myoelectric Signals. J. Biomed. Eng. 23(1)：225-229.

Yichao T, Haishu D, Fenghua T (2004). Measuring Human Tissue Oxygenation With Near Infrared Spectroscopy. Journal of Tsinghua University Sci. Technol. 44(6): 847-851 (in Chinese).