COMPARISON OF THE FREQUENCY SPECTRA OF SURFACE ELECTROMYOGRAPHIC SIGNALS FROM THE SOLEUS MUSCLE UNDER NORMAL AND ALTERED SENSORY ENVIRONMENTS

Shari J. Schroeder*, Charles S. Layne**, and Ruth A. Dyer*
* Department of Electrical and Computer Engineering, ** Department of Kinesiology,
Kansas State University, Manhattan, KS 66506

KEYWORDS

Surface EMG, Soleus, Power spectrum, Mean frequency, Median frequency

ABSTRACT

The vestibular, proprioceptive and visual senses of the body are all affected by alterations of the normal sensory environment during weightlessness. This study was designed to observe muscle activation characteristics when a single component of the sensory environment was altered. Partially immersing a subject in a water pool provided a buoyant force upon the lower body, "unloading" the muscles, similar to the effect on the muscles in weightlessness. Surface EMG from the soleus was obtained during the performance of a constant-force isometric contraction. The mean and median characteristic frequencies were calculated from the power spectrum of each trial. Six of ten subjects showed a difference in the characteristic frequencies between the two environments. It appears that for some individuals there are changes in muscle activation characteristics due to influences of the proprioceptive system when exposed to an altered sensory environment.

INTRODUCTION

In the weightless environment of space, the body is subjected to numerous alterations of its normal sensory environment. The vestibular, proprioceptive and visual senses are all affected to some degree. Some of the effects of weightlessness on the body result from a combination of the changes that occur in these senses. It is sometimes difficult to discern the role that an individual sense may play in a particular effect produced by the weightless environment. For example, weightlessness is thought to produce changes in the action of the muscle mechano-receptors and consequently changes in how the muscles are activated (1,2). The roles that each of the senses may play in these changes are not known.

This study was designed to observe potential changes resulting from the alteration of a single sensory factor on the muscle activation characteristics of postural muscles. The proprioceptive system was chosen as the component of the postural control system which would experience the altered sensory factor. Immersing the lower body in water will provide a buoyant force, counteracting the normal gravitational force felt by the lower body. The buoyant force results in an "unloading" of the muscles, similar to the "unloading" experienced in a weightless environment. The surface electromyographic (EMG) signal from the soleus muscle was obtained during the performance of a constant-force, isometric contraction. The contraction was performed with the lower body in either normal gravity or an altered sensory environment. The frequency spectrum of the EMG from each trial was calculated. Shifts occurring in the frequency spectrum, observed by a change of the mean and median characteristic frequencies, may be attributable to alterations in the proprioceptive influences on muscle activation characteristics. It was hypothesized that a difference would be found in the characteristic frequencies of the EMG signals collected under the two conditions.

Previous work has been done in monitoring the characteristic frequencies of EMG, particularly as a result of fatigue (2-8). When using the frequency spectrum to look for changes in muscle activation characteristics due to alterations of the proprioceptive system while experiencing an altered sensory environment, it is necessary to control as much as possible the other factors that are known to cause changes in the frequency spectrum. An isometric contraction will help prevent changes in electrode position relative to the active motor unit fibers. A constant-force contraction will limit the number of active motor units. These motor units are expected to remain active throughout the contraction (6) . A submaximal contraction performed for a period of less than five seconds will limit the possibility of synchronization of motor unit action potentials (MUAPs), reduce the possibility of alterations of the conduction velocity and lessen effects due to fatigue.

EXPERIMENTAL METHOD

EXPERIMENTAL SETUP

Active bipolar differential electrodes coupled to an isolated amplifier system, developed by Carlo DeLuca, Boston University Neuromuscular Research Lab (3,9), were used to collect EMG signals from the medial soleus and gastrocnemius muscles. Brief isometric contractions of constant-force, with a bent knee, activate primarily the soleus muscle (10,11). Because of the possibility of cross-talk in the detected signal, activity of the gastrocnemius muscle was also monitored. Extensions, approximately 6 feet in length, were made to the bipolar electrode leads, using the same type of cable and connectors as that used on the electrodes, so that the isolated amplifier could be placed away from the water pool.

Eleven female subjects ranging in age from 21 to 35 were tested. Each subject performed the contractions on land and in the water, while seated in the floatation chair with the foot placed on the force meter. The subjects wore chest-high, stocking-footed waders to keep the leg dry and also to maintain an even body temperature when the subject went from land to water or vice versa. Water temperature was maintained at 27 - 28 °C. The subjects were randomly assigned to be tested in the water or on land first. An initial set of five maximal voluntary contractions (MVC), separated by periods of 60 seconds of rest, were performed on land. These were averaged and a submaximal 40% MVC contraction level was calculated. The testing sequence consisted of the collection of ten acceptable 40% MVC contractions, with 30 second rest periods between each. The subject got out of the chair and the chair was placed in or removed from the pool. The subject performed a MVC and then repeated the testing sequence. Approximately ten minutes elapsed when changing from one environment to the other before the next set of 40% MVC contractions were performed. Figure 1 shows a subject seated in the water pool. Figure 2 shows a block diagram of the experimental setup.

DATA COLLECTION

EMG and force data were collected at a sampling rate of 1 kHz. Trials which did not contain a minimum interval of 2.048 sec during which the force of contraction corresponding to the 40% (+5% or -5%) MVC level was

Figure 1. Photograph of subject seated in the specially designed tloatation chair, immersed in water to the level of the hips. Subject receives visual feedback of contraction force level applied to plate from analog meter display case sitting on the side of water pool.

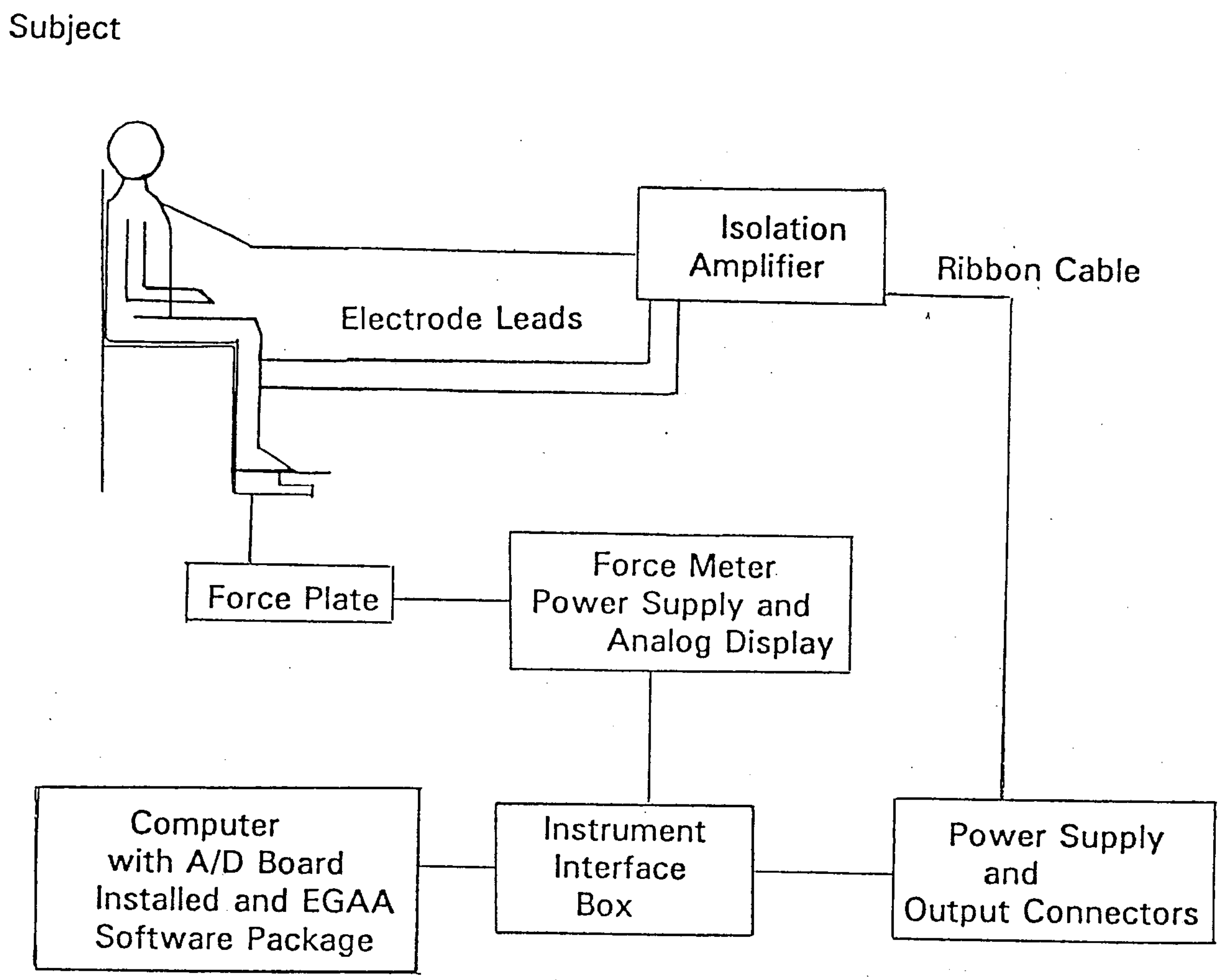


Figure 2. Block diagram of experimental setup.

achieved and held were discarded. The time interval in which the force was held at the 40% MVC level was noted for trials meeting the minimum 2.048 second interval.

FREQUENCY ANALYSIS OF EMG SIGNALS

A 2,048 point fast Fourier Transform (FFT) was performed on an interval of the EMG collected from the soleus muscle, for each trial in which the force was held constant as noted previously. The characteristic frequencies (mean and median) were calculated by the Digital Spectral Analysis (DSA) program (12,13).

T-TEST

A t-test for independent samples of unequal variance was performed on each subject's soleus muscle characteristic frequencies with a confidence interval ($1-\alpha$) of 95%, where $\alpha = 0.05$. (Note: Data from subject 3 was discarded due to equipment malfunction.) The following null hypothesis and alternative hypotheses were considered.

H_o: $\mu_{water}-\mu_{land} = 0$ versus H_{a1}: $\mu_{water}-\mu_{land} \neq 0$

H_{a2}: $\mu_{water}-\mu_{land} > 0$

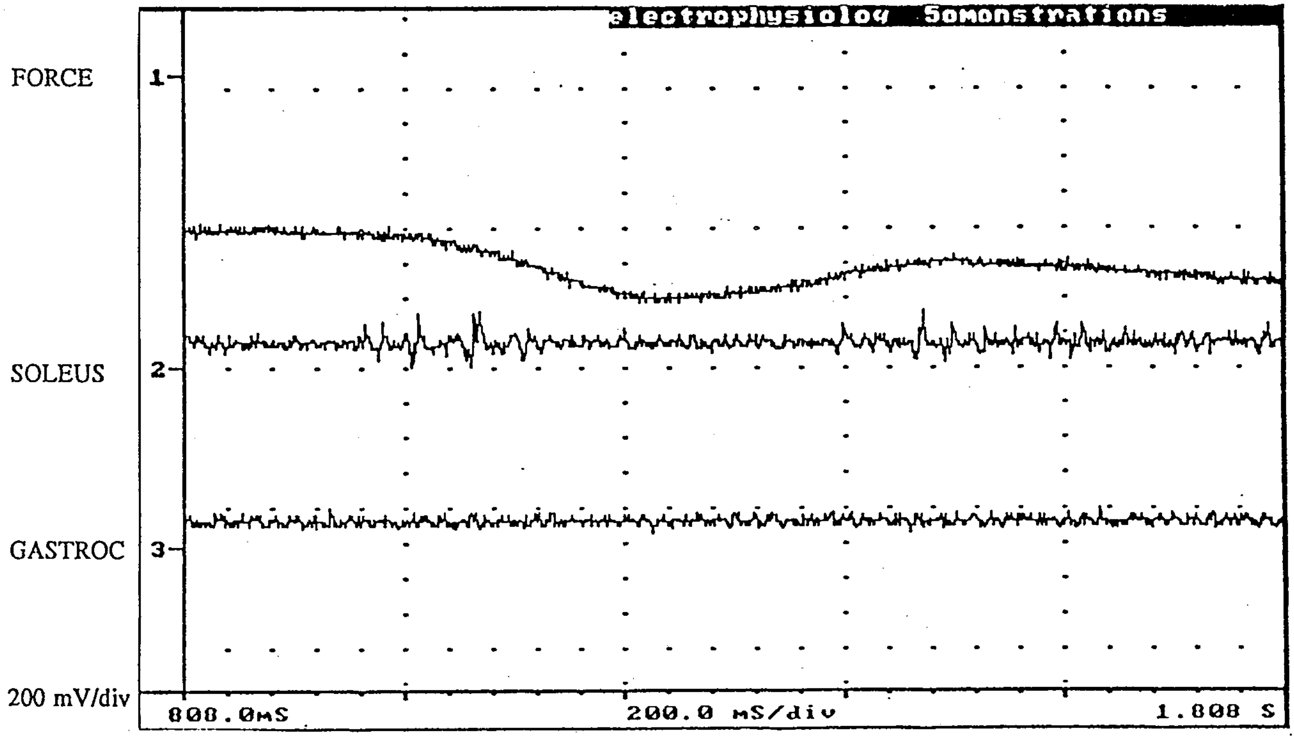
H_{a3}: $\mu_{water}-\mu_{land} < 0$

RESULTS

Figure 3 shows data collected from the force meter (channel one), the soleus EMG (channel two) and the gastrocnemius EMG (channel three) during the performance of an isometric contraction. Channel one shows a voltage that is proportional to the force produced by the contraction. As the force increases, the voltage displayed decreases. Channel two shows bursts of activity by the soleus muscle corresponding to periods of increased force applied to the meter plate. Note that although there appears to be continuous low-level activity by the gastrocnemius muscle (channel three) the activity level does not change significantly throughout the contraction. This illustrates a lack of contribution by the gastrocnemius muscle to the force produced. The gastrocnemius loses its mechanical advantage when the knee is bent.

Figures 4 and 5 are bar graphs of the characteristic frequency values from the soleus muscle for each subject and its corresponding range of one standard deviation under each environment. The subjects are grouped according to the results of the t-test. Six of the ten subjects showed a difference in the mean of the characteristic frequencies obtained from the EMG collected in an altered sensory environment and in normal gravity. The results for both the mean and median characteristic frequencies were similar for each subject. Four of the subjects exhibited a mean frequency in water greater than that on land. These same four subjects exhibited a higher median frequency in water than on land. Two of the other subjects had a higher mean frequency on land than in the water. One of these also had a higher median frequency on land than in the water. There appear to be no differences in the results of the t-test due to the order in which the subjects were tested in the two environments. Repeating the t-test on only the last five trials, which correspond to a longer adjustment to each environment before data collection, showed results similar to those of the total ten trials.

The characteristic frequencies from the gastrocnemius muscle were subjected to the same t-test as those of the soleus muscle. Although it is believed that the gastrocnemius muscle was not contributing significantly to the force of contraction (as shown in Figure 3) some activity was observed during the contractions. It was interesting to see that the gastrocnemius muscle showed very similar results to those of the soleus muscle. This may indicate


electrophysiolog Somonstrations
FORCE
SOLEUS
GASTROC
1
2
3
200 mV/div
808.0mS
200.0 mS/div
1.808 S

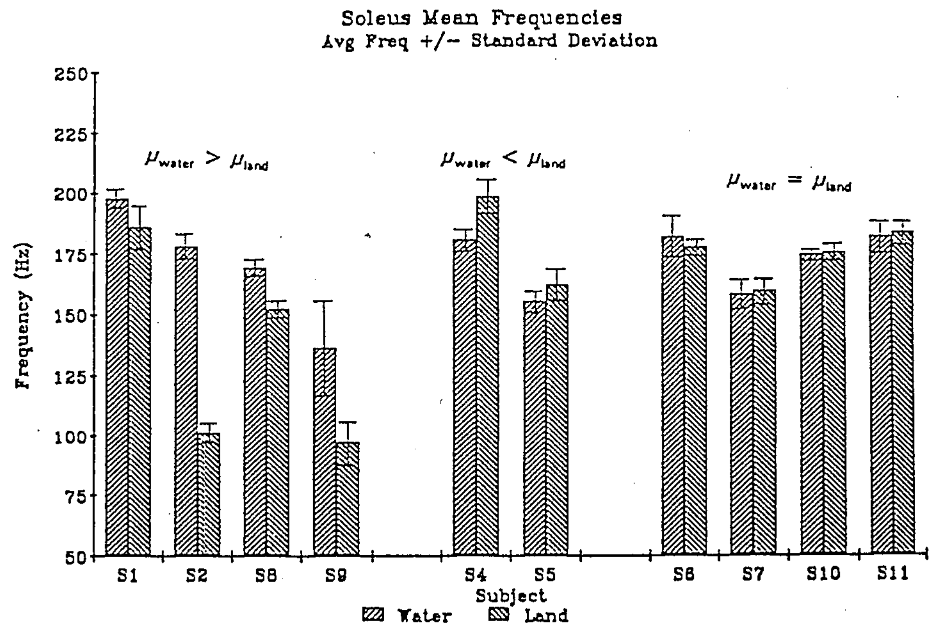


Figure 4. Mean frequency of the soleus muscle averaged over trials from each environment for each subject. One standard deviation noted. Subjects grouped according to the results of the t-test.

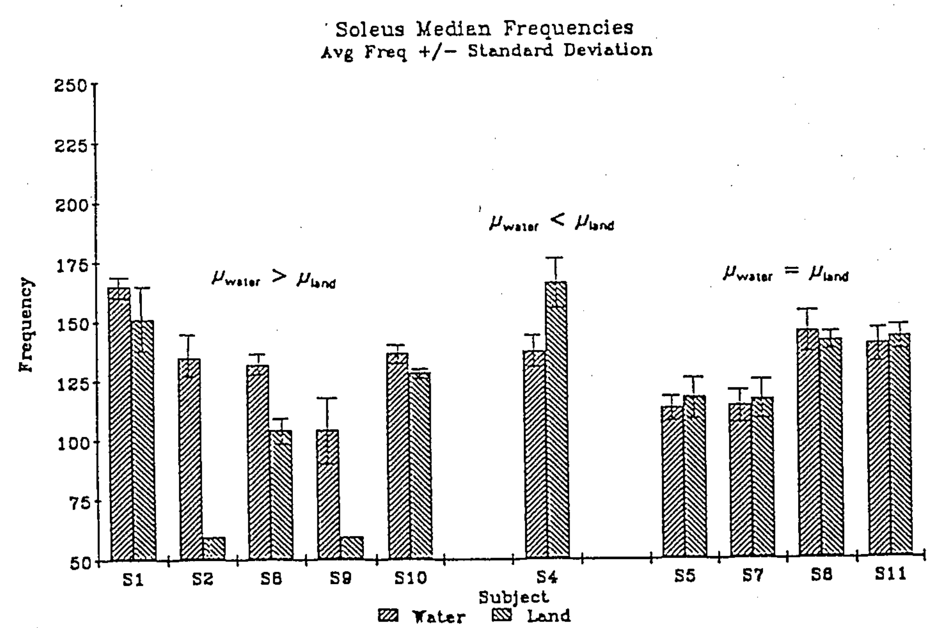


Figure 5. Median frequency of the soleus muscle averaged over trials from each environment for each subject. One standard deviation noted. Subjects grouped according to the results of the t-test.

that whatever changes occurring within the proprioceptive system on the soleus muscle activatio: are also affecting the muscle activation characteristics of the gastrocnemius muscle.

CONCLUSIONS

It appears that for some individuals there are changes in muscle activation characteristics due to i proprioceptive system when exposed to an altered sensory environment. Based on the results (the characteristic frequencies of the soleus muscle, six of the ten subjects showed a difference in tl frequencies between the two environments. Thus, at least for some individuals, changes proprioceptive input result in changes in muscle activation characteristics.

REFERENCES

1. Roll,J.P., "Body proprioceptive references in weightlessness as studied by muscle tendo: *Proceedings of the Fourth European Symposium on Life Sciences Research in Space, (I*
2. Layne,Charles S. and Spooner,Brian S.,"EMG Analysis of Human Postural Responses D Flight Microgravity Episodes," *Aviation, Space and Environmental Medicine*, Vol.61, 199
3. Basmajian,J.V. and DeLuca,Carlo J., *Muscles Alive, Their Functions Revealed by Electr* Ed.5, Williams & Wilkins, Baltimore, MD, 1985.
4. Boman,H., Bilotto,G., and DeLuca,C.J., "Myoelectric signal conduction velocity and sp parameters: influence of force and time," *J. Appl. Physiol.*, Vol.58, 1985, pp.1428-143
5. DeLuca,C.J., Sabbahi,M.A., Stulen,F.B., and Bilotto,G., "Some properties of the medi: of the myoelectric signal during localized muscular fatigue," In Knuttgen HK et al., *Bio Exercise*, Vol.13, 1983, pp.175-186.
6. DeLuca,C.J. and Forrest,W.J., "Some properties of motor unit action potential trains re constant force isometric contractions in man," *Kybernetik*, Vol.12, 1973, pp.160-168.
7. Sadoyama,T., Masuda,T., and Miyano,H., "Relationships Between Muscle Fibre Condu and Frequency Parameters of Surface EMG During Sustained Contraction," *Eur. J. App* Vol.51, 1983, pp.247-256.
8. Tarkka,I.M., "Power Spectrum of Electromyography in Arm and Leg Muscles During Is Contractions and Fatigue," *J. Sports Med.*, Vol.24, 1984, pp.189-194.
9. *EMG Surface Electrode Specifications*, NeuroMuscular Research Center,Boston University,
10. Herman,R. and Bragin,S.J., "Function of the gastrocnemius and soleus muscles," *J. Am. Assoc.*, Vol.47, 1967, pp.105-113.
11. Rasch,Philip, *Kinesiology and Applied Anatomy*, Ed.7, Lea & Febiger, Philadelphia,PA,
12. Lopez,Estell, "Spectral Analysis of Electromyographic Signals Using Autoregressive Mo A Master's Thesis, Kansas State University, Manhattan, KS 1990.
13. Teshome,Abeye, "Spectral Estimation of Electromyographic signals Using the Discrete S Fourier Transform," A Master's Thesis, Kansas State University, Manhattan, KS 1990.