Effects of Training Upon Cervical Muscle Strength and Endurance and Upon Electromyographic Potentials

by

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ABSTRACT

A qualitative evaluation was made concerning the effectiveness of a progressive resistance training program upon increasing the endurance capabilities of the muscles in the neck region. In order to minimize the effects of psychological factors entering into the evaluation, a fatigue index was chosen which utilized the electromyographic (EMG) signal obtained from the contracting muscle.

Prior investigations have shown that it is possible to determine the degree of fatigue in a muscle by using frequency analysis of the electromyogram. More specifically, if the mean power frequency (MPF) of the Fourier power spectra is used as an index of the EMG frequency, a linear decay of the MPF is seen to occur over the course of time. In addition, the slope coefficient of the MPF-time curve has been shown to correlate well with the endurance time associated with the contraction.

In this study, the change in the MPF slope coefficient occurring over a 4 week period was measured for a training and nontraining group. The results obtained show that a statistically significant difference existed between the change in MPF slope coefficient for the training and nontraining groups and should reflect upon the increase in endurance capabilities achieved by the training group over the nontraining group. Due to the length and overall nature of the training program, it was concluded that an increase in motor control was primarily responsible for producing the endurance changes seen in this study.

INTRODUCTION

"When the tension exerted by a muscle is less than 10-15% of the muscle's maximum voluntary contraction (MVC), the contraction is said to be nonfatiguing and can be sustained for an indefinite length of time." (32) When an isometric contraction is held at tensions greater than 15% of the muscle's MVC, the time the contraction may be held (endurance time) is quite short.

Maintaining the head in an erect position is a form of pure isometric exercise. The fatiguing effects of this exercise may become significantly magnified when a load is placed upon the head. Such is often the case with Army personnel, who must wear a protective helmet, and are often required to wear additional equipment such as night vision goggles and electronic sighting systems. Furthermore, when these factors are in concurrence with whole body vibration, like that produced in helicopters and land vehicles, the occurrence of fatigue is even more prevalent. (14,15)

Several investigations have already been conducted to quantify the effects of helmet loading upon the muscles of the neck region as well as the "fatigue endpoint" for these muscles. (14,15,32,33,34) These studies have attempted to define limits of safety for various helmet loading configurations and should significantly aid in the design of forthcoming equipment which is to be placed upon the heads of military personnel. No work, however, has yet to be done in the area of increasing the endurance of the muscles in the neck region. Since the design and manufacturing of new equipment is very costly, the need exists to study the effects that a training program would have on the strength and endurance levels of the neck muscles.

"The application of a progressive resistance exercise can be expected to increase strength of various muscle groups when applied over some six weeks or longer." (9) Increasing endurance levels in skeletal muscle have also been noted when an exercise program was administered. (4,7,12,35) This increase in strength and endurance would be expected due to biochemical adaptations which occur in skeletal muscle as a result of exercise, leading to an increase in capacity for aerobic metabolism. (13) Another important mechanism associated with increasing endurance due to training is a psychological adaptation to the discomfort felt while maintaining a contraction. (5) Since the purpose of this study was concerned only with the physiological changes occurring in a muscle as a result of training, a method of endurance evaluation was needed which would exclude the influence of psychological factors. The use of the electromyographic signals from the fatiguing muscle could provide this necessary information.

Electromyography (EMG):

"While the muscle fiber is considered to be the fundamental substrate of muscle morphology, the motor unit is the functional (neuromotor) one." (1) A motor unit is defined as the motor neuron, its axon and branches, and the fibers they intervate. In normal mammalian skeletal muscle, muscle fibers never contract individually; they are part of a motor unit, all of whose fibers contract almost simultaneously during a brief twitch. (1) When an impulse from the spinal cord reaches the motor endplate, a minute electrical potential is developed with a duration of 1-2 msec. This signal is then dissipated into the surrounding tissue. Since all muscle fibers do not contract at exactly the same time, a resultant electrical potential is developed with a duration of between 5-12 msec and an amplitude of up to 500 microvolts. "With surface electrodes the durations are prolonged as the potentials are "blurred" and rounded out". (1) Despite this fact, surface electrodes provide a good, noninvasive reflection of the motor unit activity over a considerable area of muscle and should adequately represent the activity within the entire muscle.

In the last 25 years, the use of quantitative EMG to assess muscle tension and fatigue has become an extremely useful tool. Bigland and Lippold (2), Edwards and Lippold (10), and Milner-Brown and Stein (27) have all found a linear relationship between the tension exerted by a muscle and the integrated or root mean square amplitude of the EMG.

Using selective frequency filtering techniques, it is possible to determine the degree of fatigue in a muscle during an isometric contraction. Using the center frequency of the Fourier power spectra as an index of the EMG frequency, several authors have found a linear decrease in the mean power frequency (MPF) during the course of fatigue when sustaining submaximal contractions between 25-100% of the MVC. (24,31, 39) Petrofsky and Lind (31) have also found that the center frequency of the power spectra decreases to the same point, before levelling off at the point where the target tension can no longer be held, irrespective of the tension exerted by the muscle during the contraction. The rate of change of the MPF has also been shown to correlate well with the load generated in the muscle as well as with the endurance time associated with the contraction. (11,22,30) Therefore any change in the MPF slope coefficient produced by a training program should reflect upon the physiological changes which occurred in the muscle as a result of the training, and would give a qualitative measure of the changes in endurance capabilities of the muscle group in question.

The purpose of this investigation was that of a pilot study, to examine in a qualitative manner only, whether or not a progressive resistance training program could produce a significant change in the isometric endurance of the neck muscles.

MATERIALS AND METHODS

Subjects: Seven healthy subjects, 3 females and 4 males (mean age:19.0; range:18-23), volunteered to take part in this investigation. Four of the subjects volunteered to undergo training, while the remaining three were used as a control group. All subjects were thoroughly informed of the experimental procedures and signed a consent form stating this fact.

Isometric Strength and Endurance: All measurements were performed while the subjects were in a seated position, as shown in Fig. 1, with their heads held vertically. A harness was fitted to each subject's head and proper adjustments were made to allow for the isometric force to be applied perpendicular to the force transducer. The subject was also strapped to a chest brace to prevent the use of his back in contributing to the contraction force.

Prior to any training, each subject was required to produce a

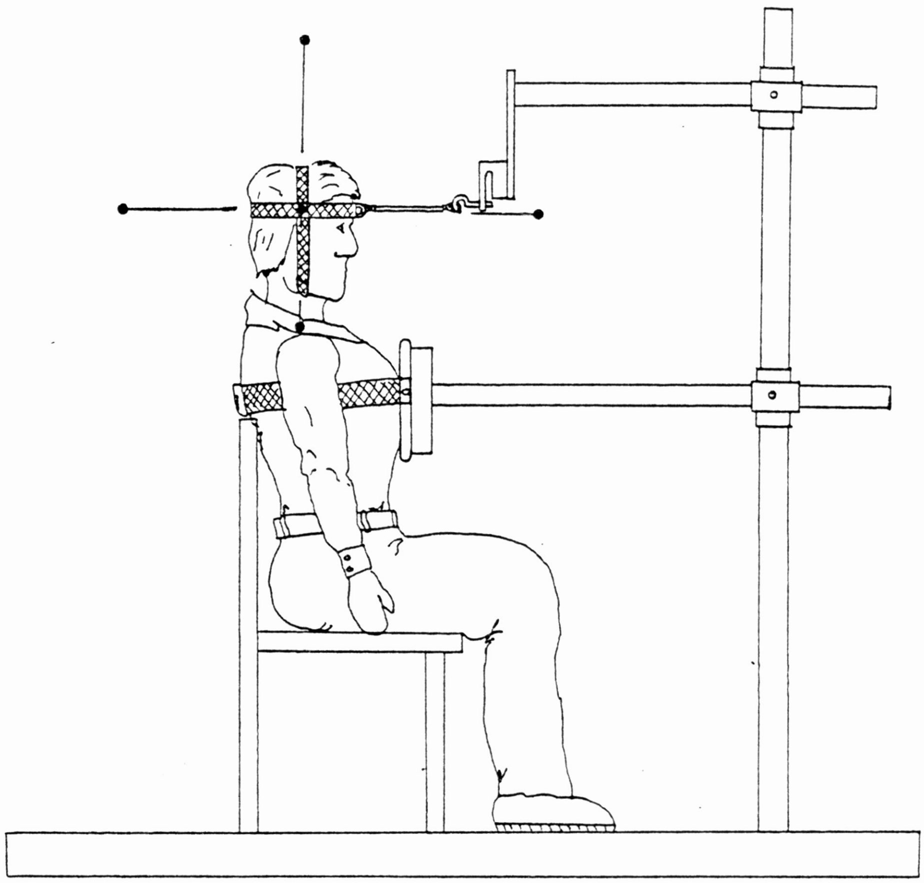

FIG. 1. Subject seated in isometric dynamometer.

dorsally directed MVC, which was recorded as the larger of two successive attempts. The exerted force was transmitted through a force transducer (Genisco, AWU-300), amplified by a Grass low level DC amplifier, and recorded on an Omnigraphic XY-recorder. The entire force transducing system (transducer, amplifier and recorder) was initially calibrated using dead weights and was found to be linear over the range of operation (0-333.6N). The system was also calibrated before each endurance recording session using a two point, dead weight calibration. Following the MVC exertion, the subjects were allowed to rest for approximately 5 minutes. Next they were instructed to maintain an isometric contraction at a level of 70% of their individual MVC for a period of 21 seconds or until fatigued, which ever occurred first.

Visual feedback concerning the level of the contraction was provided to the subjects by the XY-recorder which was placed directly in front of them. The subjects were constantly motivated to sustain the contraction by means of verbal encouragement.

Electromyography: The myoelectric signals were picked up from the subjects by two electrodes (Beckman silver-silver chloride, 6mm contact diameter, 2.0 cm center-to-center inter-electrode distance). The electrode site was prepared according to methods described by Johnson, et al. (16). The active electrodes were initially placed over the trapezius muscle, on the right side of the vertebral column, which was located by palpating the neck region (Fig. 2). Once the electrodes

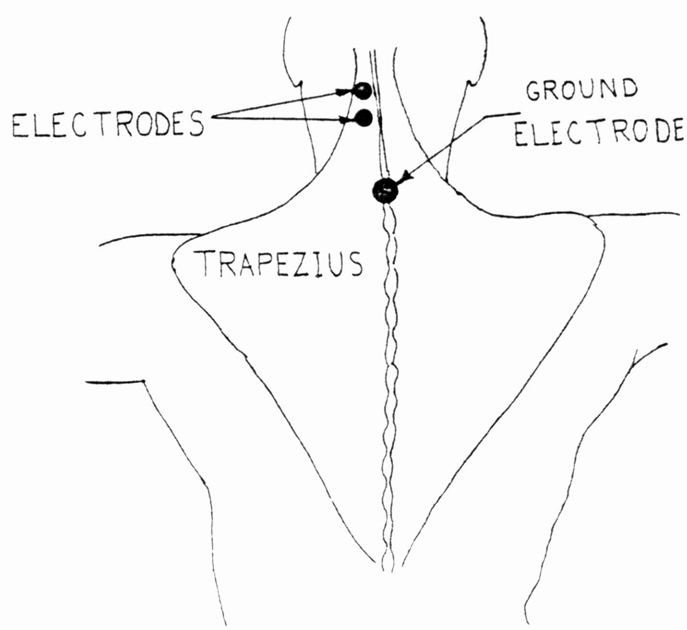

FIG. 2 Placement of surface electrodes on subject.

were in place, the vertical distance from the T-1 vertebrae to the center of the top electrode was measured and recorded along with the horizontal location of the electrodes with respect to the centerline of the vertebral column, so that the electrodes could be placed in the same proximity each time an endurance recording was to be made on the same subject. In addition to the two active electrodes, an additional reference (ground) electrode was applied above the process of the T-1 vertebrae.

Once all electrodes were successfully attached to the subject, the electrode leads were connected into a Grass P5 Series AC Pre-amplifier for initial checkout. The electromyographic signal was observed and a subjective analysis of its quality was made, looking specifically for 60 Hz interference which might indicate a poor electrode preparation. The skin next to each electrode was vigorously tapped to check for motion artifact in the electromyographic data. An acceptable preparation was one which yielded no visible sign of disturbance in its electromyographic output. If the electrode preparation was contributing motion artifact to the EMG data, the electrode was removed and reapplied.

Instrumentation: Once a satisfactory preparation was attained, the electromyographic output was connected to a Hewlett-Packard analog-to-digital converter (sampling freq: 1024 Hz) and the digitized signal was recorded and stored on a floppy disk by a Hewlett-Packard 9836 computer. For the purpose of reducing data storage space and analysis time, the data was only sampled for the first second of each three second interval. This method of sampling may be justified by the fact that the MPF is a linear function over the course of time. (24,31,39) A Fast Fourier Transform (FFT) was performed on each second of data with a spectral averaging time of 1 second. A Hamming window was also used when performing the FFT. The MPF was then calculated from the FFT using previously described methods. (28)

Training:*

With the subject in a squatting position (Fig. 3), the maximum load which could be successfully lifted for one repetition was measured and recorded. Defining this load as the subject's MAX, the subject was instructed to follow the training program outlined below:

First Week: 3 sets of 10 repetition at 50% MAX

Second Week: 3 sets of 8 repetition at 60% MAX

Third Week: 3 sets of 6 repetition at 70% MAX

Fourth Week: 3 sets of 4 repetition at 85% MAX

For endurance training purposes, the rest time between sets was kept relatively short (approximately 1 minute).

Following the first and fourth weeks of training, isometric endurance measurements were made in which the subjects were asked to sustain a load of 70% of their initial MVC (that which was recorded prior to any training). Electromyographic recordings were made using the procedure described above in the section titled "Electromyography".

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*The progressive resistance training program which was administered to the subjects was suggested by Joe Debella, a graduate student in the Department of Health and Physical Education and weight training instructor at Texas A&M University.

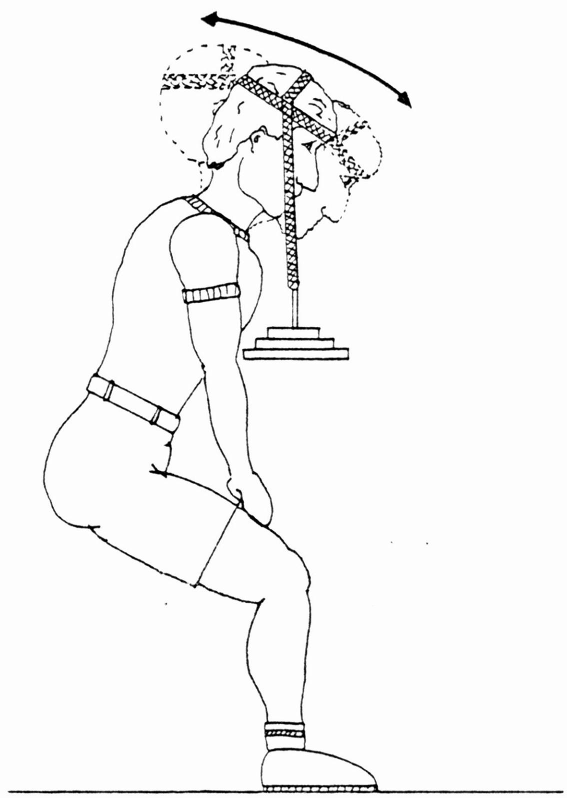

FIG. 3 Position of a subject while performing isometric exercises.

RESULTS

A typical example of the EMG signal obtained from a subject during a fatiguing contraction may be seen in Fig. 4a and 4b for the unfatigued and fatigued cases, respectively. The characteristic signs of muscle fatigue, such as increase in amplitude, loss of high frequency motor components, and motor unit sychronization are easily observed. In Appendix A, the normalized power spectra are shown for each subject along with the corresponding plots of MPF vs. time. In

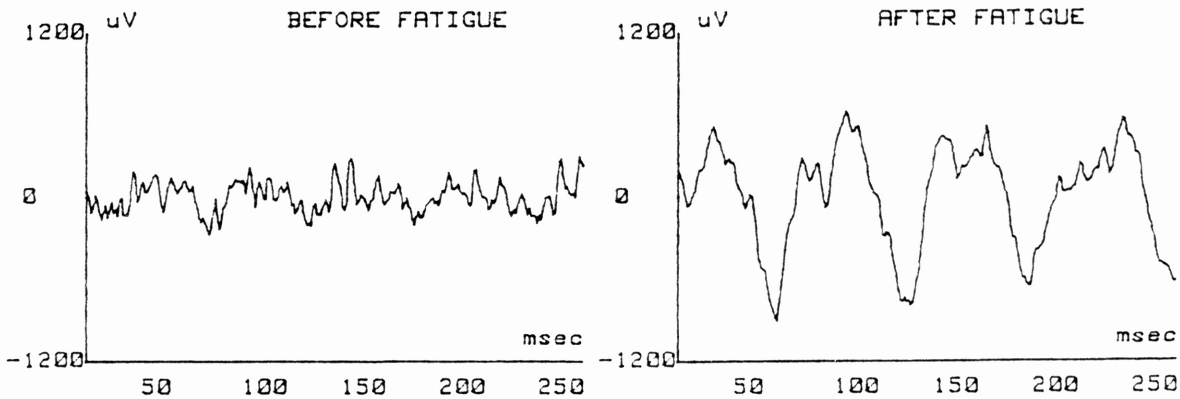

FIG 4 Sample of electromyographic signal obtained for a fatiguing contraction a) during the first 250 msec and b) during the last 250 msec of an isometric contraction.

all cases the correlation coefficient (r) for the linear regression curve through the MPF values was greater than 0.88 and the average correlation coefficient was 0.96. It can be readily seen that in all cases the power spectra has shifted to lower frequencies during the course of fatigue. The linear decay of the MPF over time is also apparent in all cases. The slope coefficients, which are shown on the figures, were computed using the last n-1 data points (where n = total number of data points). This was done to eliminate any artifact which might have entered into the data as a result of some of the subjects becoming situated during the first couple of seconds of the contraction.

Δ% MPF Slope Coefficient

Training		Nontraining	
CT	-32.96	BS	1.89
EB	-21.79	JC	0.91
JM	-39.08	BM	-3.63
GS	-14.12		
X_t =	-27.02	X_{nt} =	-0.28
SD_t =	11.16	SD_{nt} =	2.94

TABLE I. Mean Power Frequency Changes for Training and Nontraining Groups.

Table I lists the percent changes in the MPF slope coefficient for all subjects along with average and standard deviation values for the training and nontraining groups, respectively. It is worth noting that training subject GS admitted that he missed a few of the training sessions, which could account for his small change in slope with respect to the other training subjects. Although this data could be eliminated on the basis of Chauvenet's criterion, the test for statistical significance was carried out with this data included.

Statistical Significance: If the null hypothesis, which assumes that training has no significant effect upon the change in the MPF slope coefficient, is formed, the alternate hypothesis would state that training does have an effect upon the MPF slope coefficient. To test the assumed null hypothesis, a two sided means tests for two independent samples with known standard deviations was applied (3). Using a level of significance of 0.05, it was determined that the null hypothesis should be rejected, implying a statistically significant difference in the change in the MPF slope did exist between the training and nontraining groups.

DISCUSSION

The observed shift of the EMG power spectra to lower frequencies during the course of fatigue as well as the observed linear decay of the MPF over time are in agreement with previous findings. (21,23,24, 28,30,31,39) This overall shift to a lower frequency is known to occur because of a reduction in high frequency and an increase in low frequency components of the power spectra during a fatiguing contraction. (8,16,18,31) It has been suggested (17,23,29,37) that this reduction in frequency of the surface EMG is due to the accumulation of metabolites (specifically lactic acid) in the fatiguing muscle which slow down the conduction velocity of the action potentials on the muscle fibers.

The production of lactic acid occurs when the force of a contracting muscle causes the blood flow through the muscle to become partially occluded, producing a shortage of oxygen in the muscle. This lack of oxygen, in turn, causes the muscle to switch from aerobic to anaerobic metabolism as a source of energy with an end product of lactic acid. (23) In addition to an increase in lactic acid production, the negligible blood flow to a contracting muscle results in the lactic acid by-product not being washed out of the tissue.

This association between blood flow and fatigue has been further supported by studies in which the blood supply to a contracting muscle was artificially occluded. Stephens and Taylor (38) and Merton (26) showed that with a total occlusion of the blood flow to a muscle, the force that the contracting muscle was able to produce would eventually fall to zero. In natural contractions, however, the force generally falls to a level of about 25% MVC and then stabilizes for several minutes. An explanation for this occurrence (38) is that at the lower contraction strength (25% MVC), the blood flow presumably returns to the muscle in a sufficient level to allow for the contraction to continue. It should also be noted that when a fatigued muscle remains artificially occluded after the contraction has ceased, no recovery from fatigue seems to occur. In the case when the blood supply is not occluded, recovery from fatigue begins almost instantly after the contraction has ceased. It is this relationship between blood flow and fatigue which accounts for why training would produce an increase in muscular endurance.

There are many physiological changes which occur in a muscle which has been subjected to a training program. One factor associated with endurance type training is an increase in vascularization within the muscle which would allow for a greater oxygen transfer rate to the muscle. Also associated with this type of training is an increase in the myoglobin concentration within the muscle (myoglobin is an important reserve store of oxygen within the fiber and is important in the intracellular transport of oxygen). Endurance type training also produces an increase in the enzymatic activity within a muscle which provides energy for sustained muscular efforts. Another factor associated with training and increased oxygen transport is an increase in cardiac output, however, the training program administered in this study was probably not strenuous enough to affect this to any significant degree. Two other factors which are related to an increase in muscular endurance produced by a training effect are an increase in the strength properties within the muscle and an increase in motor control. The increase in strength within the muscle is a result of changes which occur in the contractile properties of the muscle fibers. This is specifically related to an increase in ATP production via an increase in the concentration of myosin ATPase, the enzyme responsible for releasing the energy in the ATP molecule.

Several authors have noted an increase in motor control as a result of a resistance training program (6,19,25,36) and Basmajian (1) states that "skilled movements are performed with an economy of muscular actions" and are associated with "minimal energy expenditures".

In evaluating which training factors were primarily responsible for the EMG shifts observed in this study, it is presumed that increased motor control is the most important factor and strength improvements play a secondary role. The endurance training factors, such as increased vascularization and increased enzyme activity, involve complex biological adaptations within the body which probably did not have time to occur during the designated four week training period used in this study.

The increase in motor control, which may produce an increase in strength by as much as 20%, may occur in a single training session when using large loads. (20) This level of increase in contraction strength would result in an apparent decrease in the tension generated within the muscle. This decrease in tension would, in turn, reduce the constriction placed on the arteries which supply blood to the muscle and thus reduce the rate at which fatigue occurred in the contracting muscle. This phenomenon would explain the reduction in MPF slope coefficient observed to occur among the training group in this study. Lamb (20) also states that it seems reasonable to assume that these motor control adaptations could "be enhanced by a long-term program of strength training".

CONCLUSIONS AND RECOMMENDATIONS

Although the results of this study indicate that the muscles of the neck region are capable of endurance training, several questions cannot be answered here. The first unanswered question involves the quantity of training these muscles are capable of. Since the present method of quantitatively evaluating muscular endurance (simply measuring the time of the contraction) is highly dependent upon psychological factors, a new method must be devised which will allow for endurance to be evaluated with respect to physiological factors only. With the present level of information, it is also impossible to define the exact mechanism associated with the increase in endurance. Perhaps further studies may reveal answers to these questions.

In attempting a larger scale study to investigate the effects of training upon muscular endurance, it is recommended that perhaps a longitudinal study be used in place of the cross sectional study which was used in this experiment. (The longitudinal study involves monitoring the same group of subjects, first as a control group and then as an experimental group). This may eliminate any possibility of selecting a training group which was more naturally endowed with athletic ability than was the control group.

In addition, in order that the mechanism by which endurance is increased may be looked at more closely, it is recommended that various physiological factors be monitored throughout the study. (These include factors such as heart rate, oxygen uptake and if possible, blood chemistry.)

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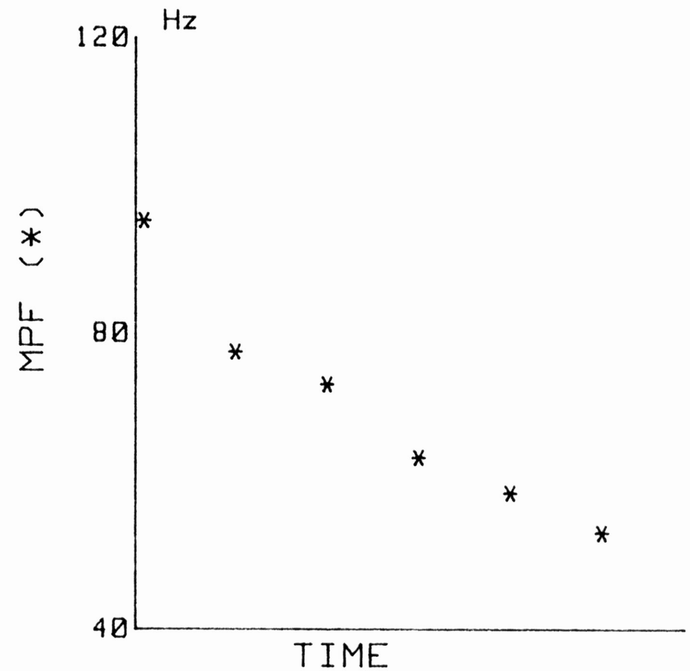
APPENDIX

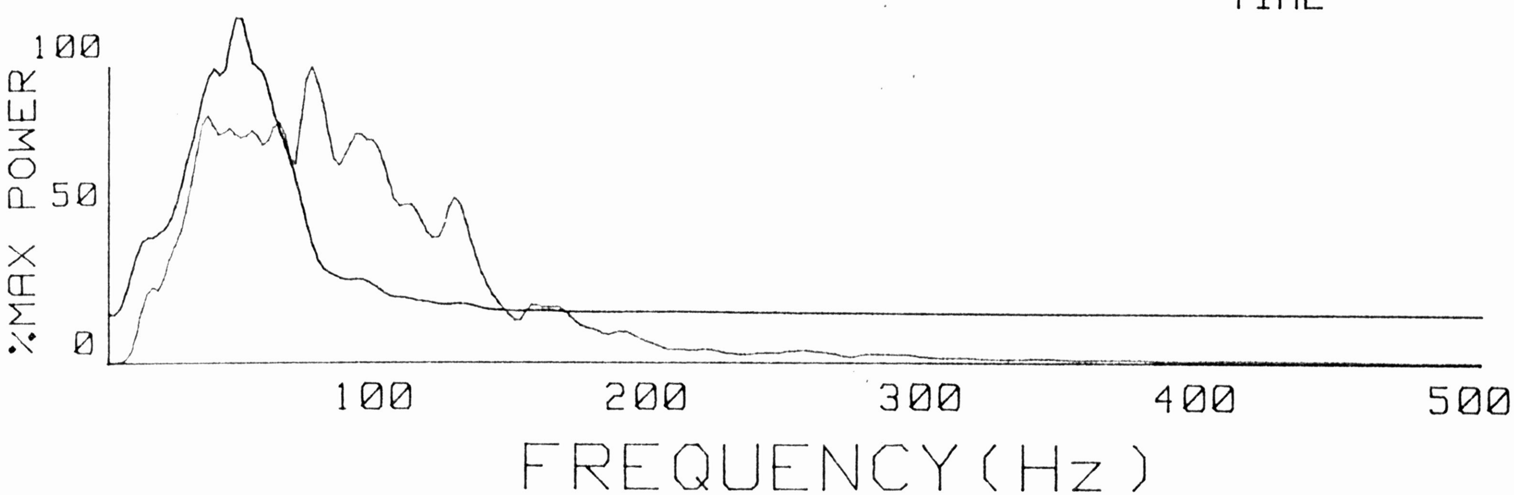
EMG POWER SPECTRA

SUBJECT:BS (INITIAL)

TIME	MPF
0.00	92.85
3.00	75.06
6.00	70.73
9.00	60.82
12.00	56.00
15.00	50.61

SLOPE OF MPF -> -2.12
INTERCEPT OF MPF -> 81.73



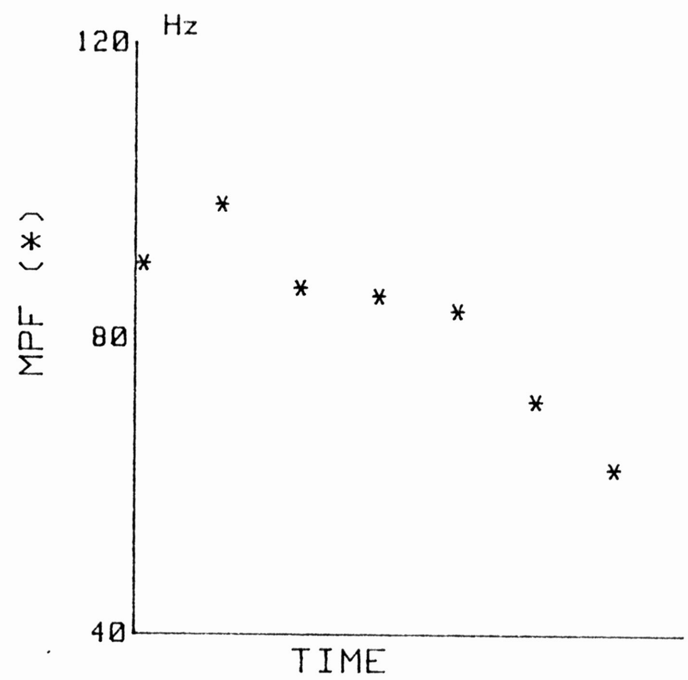


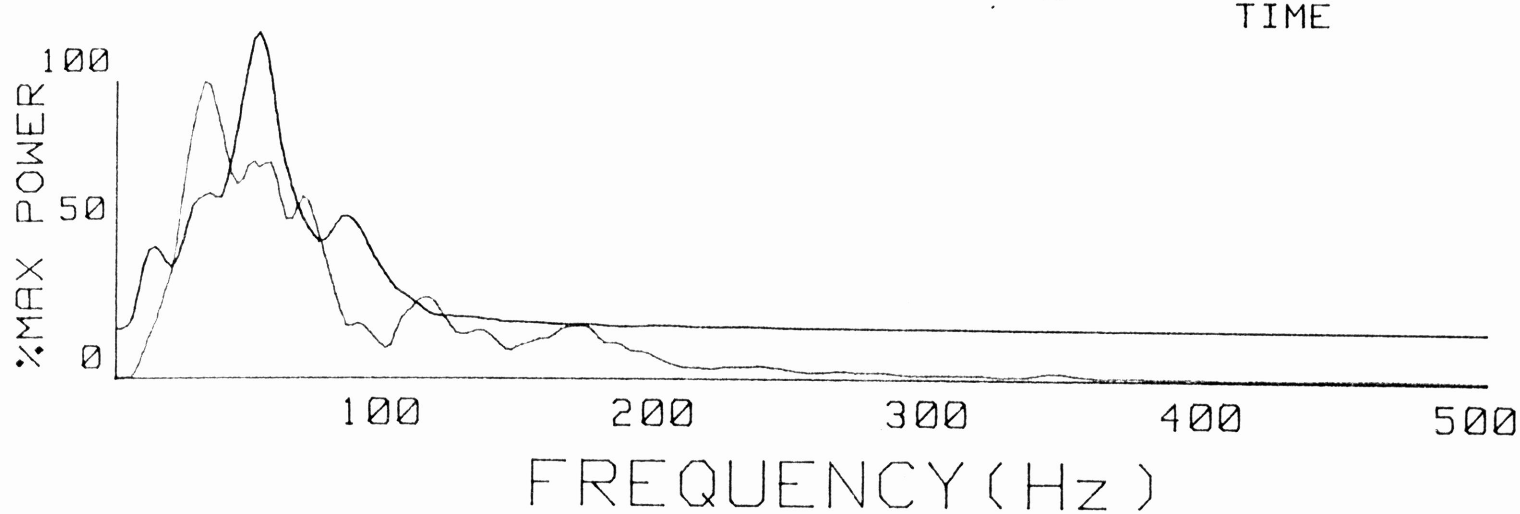
EMG POWER SPECTRA

SUBJECT:BS (FINAL)

TIME	MPF
0.00	87.78
3.00	95.81
6.00	84.51
9.00	83.41
12.00	81.39
15.00	69.19
18.00	59.95

SLOPE OF MPF -> -2.16
INTERCEPT OF MPF ->101.77



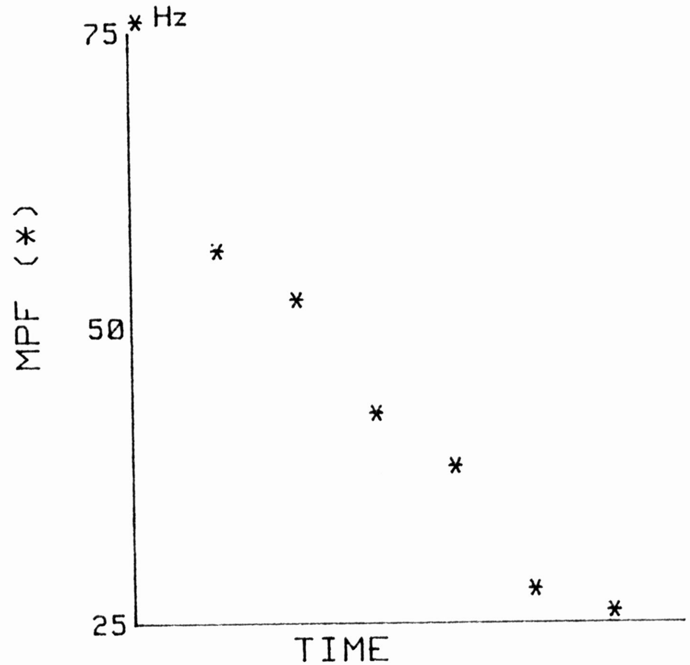


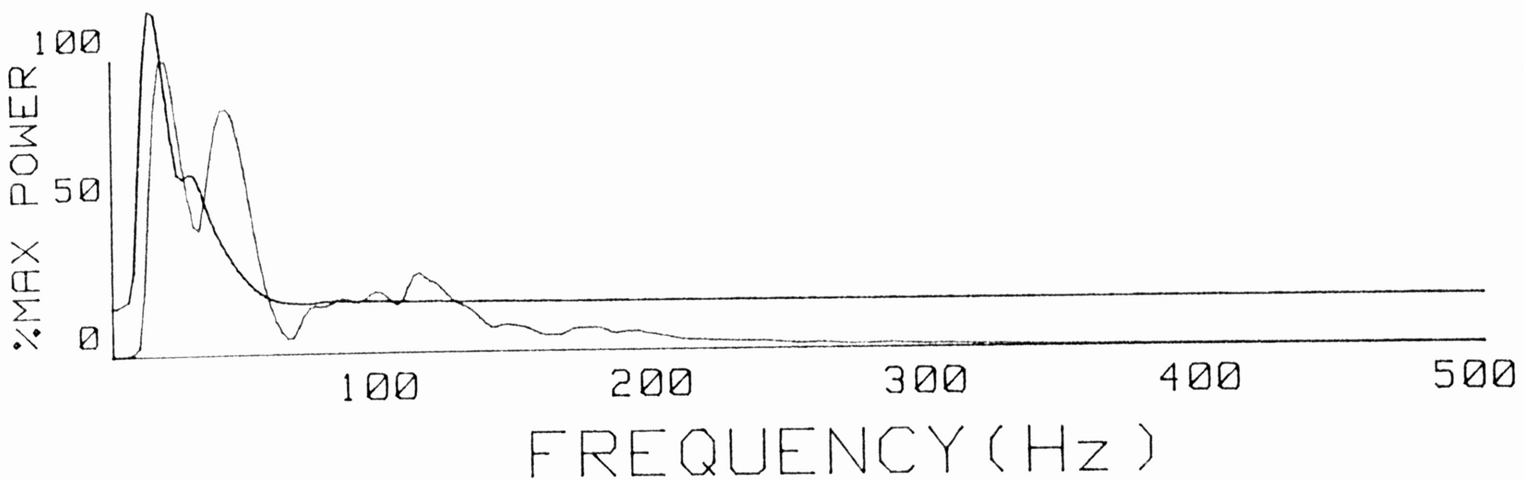
EMG POWER SPECTRA

SUBJECT:JC (INITIAL)

TIME	MPF
0.00	74.44
3.00	55.02
6.00	50.87
9.00	41.27
12.00	36.75
15.00	26.38
18.00	24.51

SLOPE OF MPF -> -2.20
INTERCEPT OF MPF -> 62.19



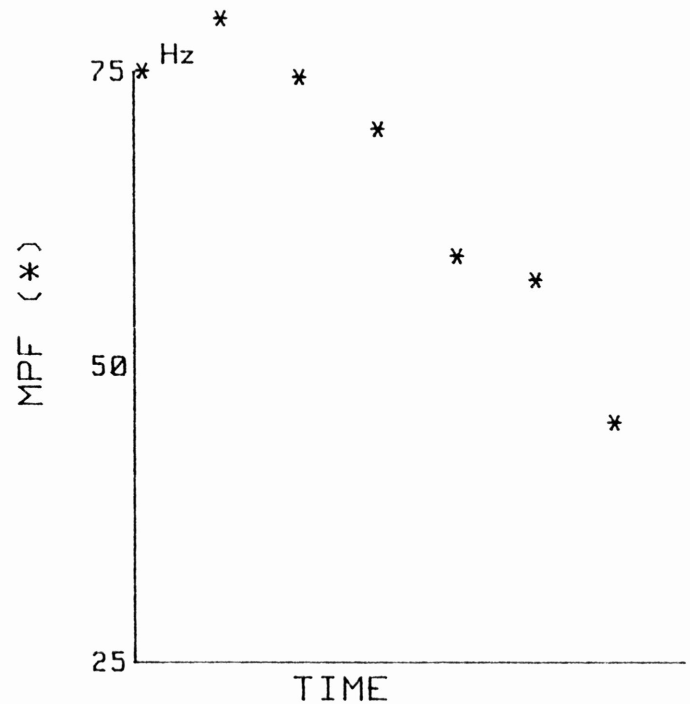


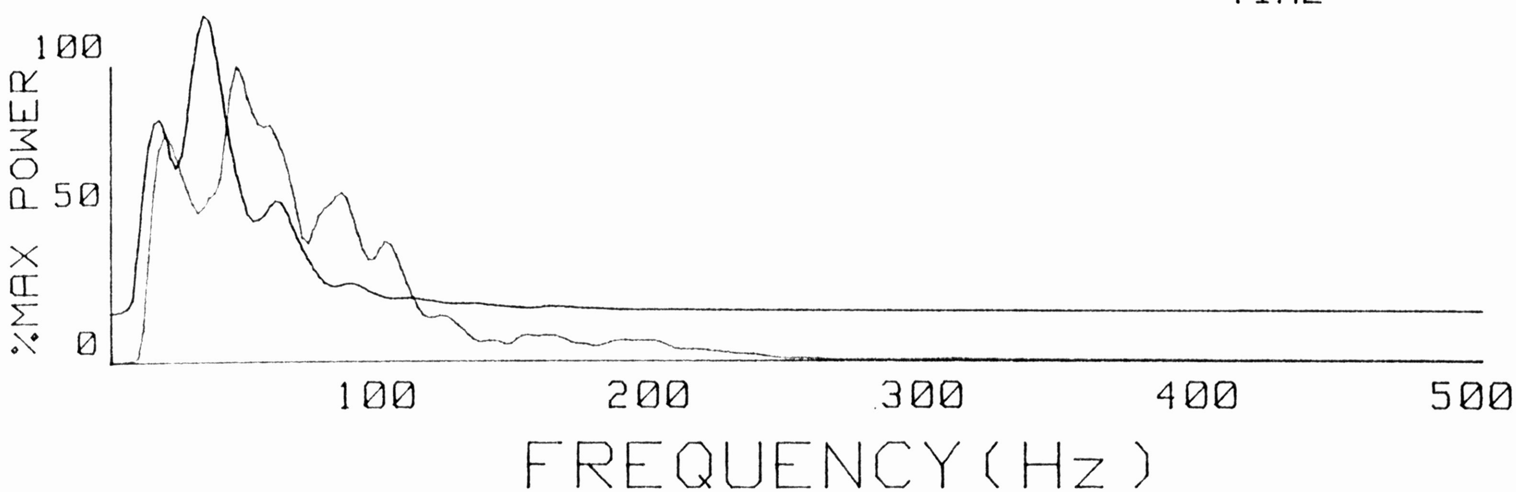
EMG POWER SPECTRA

SUBJECT:JC (FINAL)

TIME	MPF
0.00	73.55
3.00	77.97
6.00	73.01
9.00	68.59
12.00	57.87
15.00	55.83
18.00	43.80

SLOPE OF MPF -> -2.22
INTERCEPT OF MPF -> 86.16



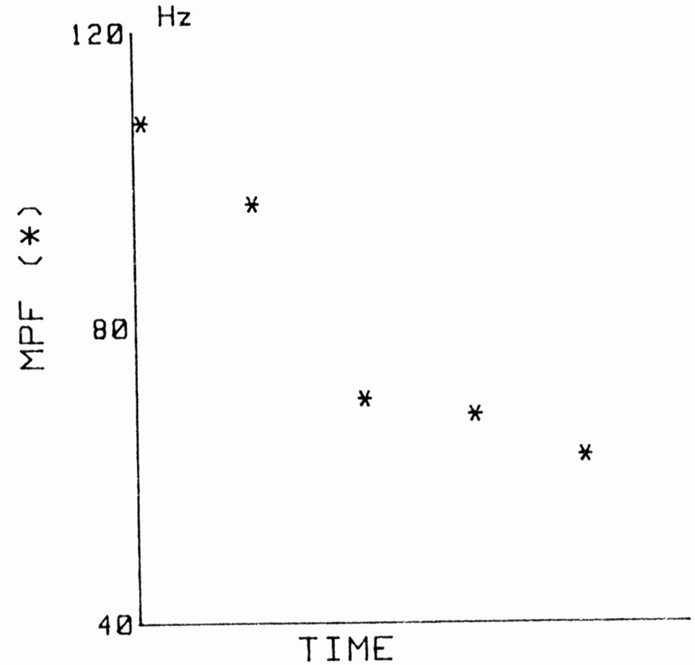


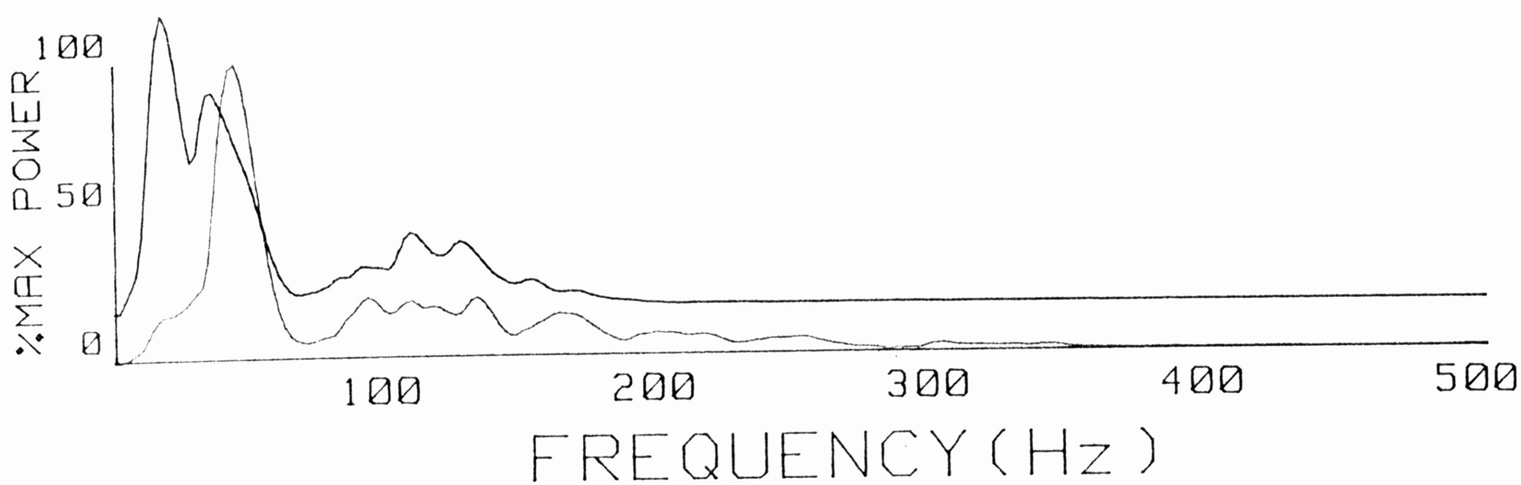
EMG POWER SPECTRA

SUBJECT:JM (INITIAL)

TIME	MPF
0.00	105.30
3.00	94.32
6.00	67.92
9.00	65.81
12.00	60.24

SLOPE OF MPF -> -3.48
INTERCEPT OF MPF -> 98.16



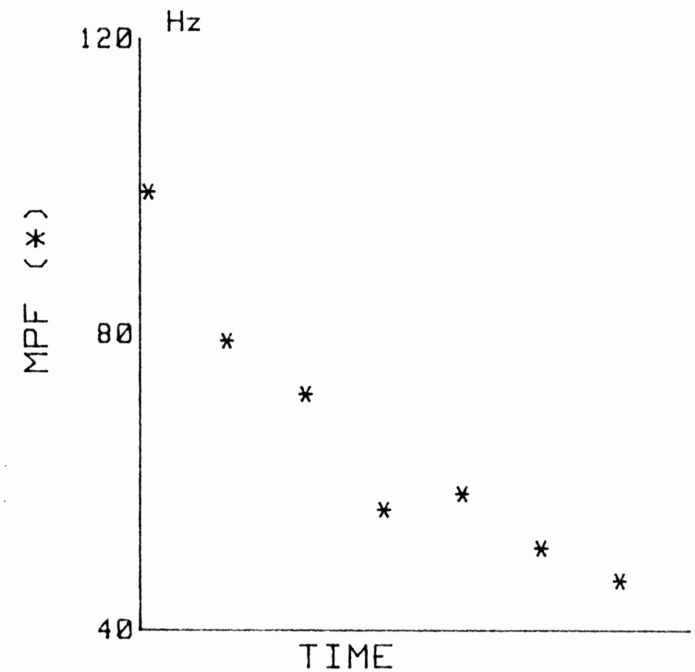


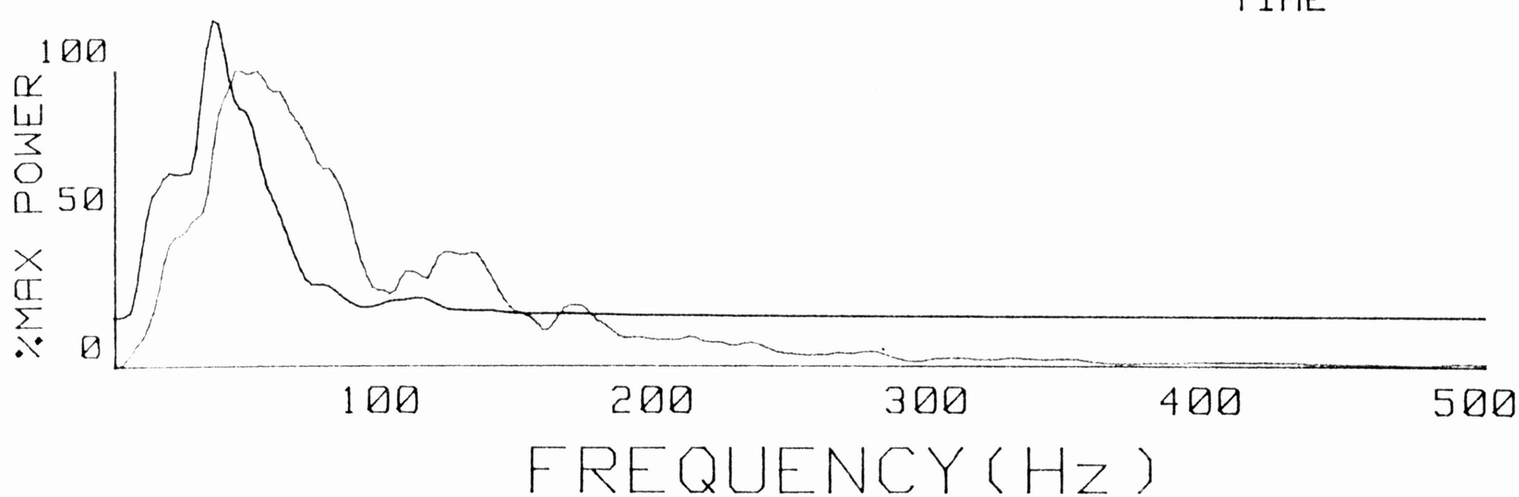
EMG POWER SPECTRA

SUBJECT:JM (FINAL)

TIME	MPF
0.00	96.87
3.00	76.72
6.00	69.57
9.00	53.92
12.00	56.03
15.00	48.70
18.00	44.29

SLOPE OF MPF -> -2.12
INTERCEPT OF MPF -> 80.47



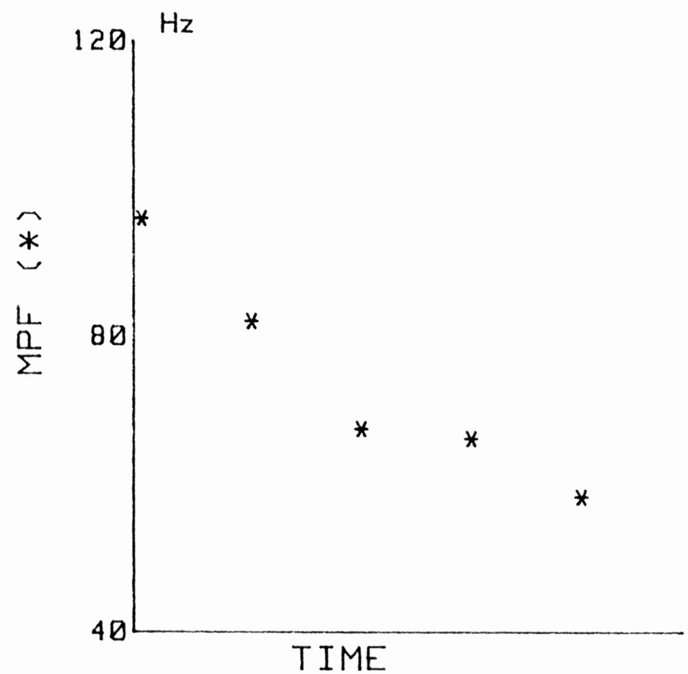


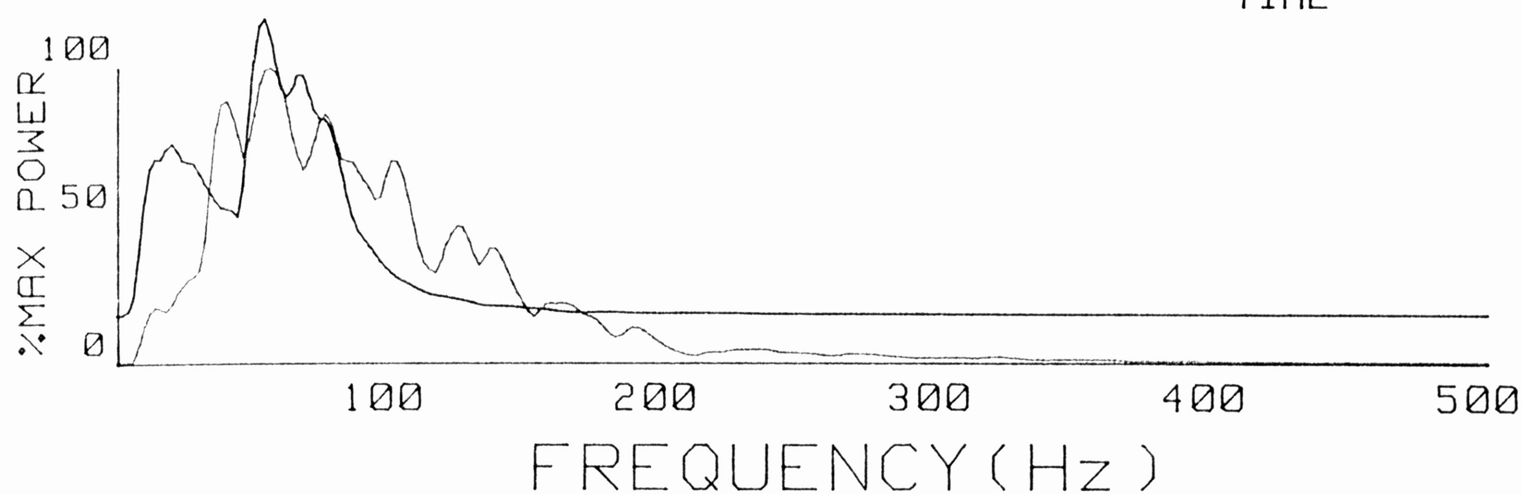
EMG POWER SPECTRA

SUBJECT:CT (FINAL)

TIME	MPF
0.00	93.57
3.00	79.62
6.00	65.05
9.00	63.73
12.00	55.82

SLOPE OF MPF -> -2.42
INTERCEPT OF MPF -> 84.23



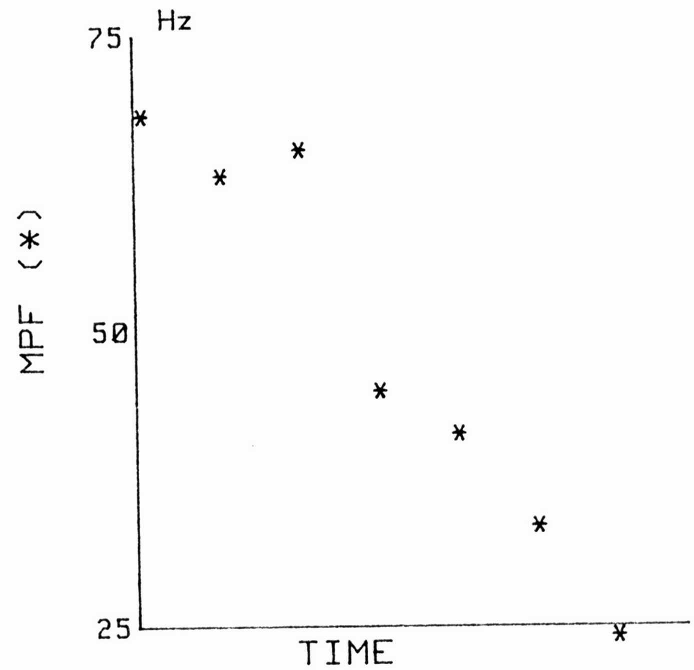


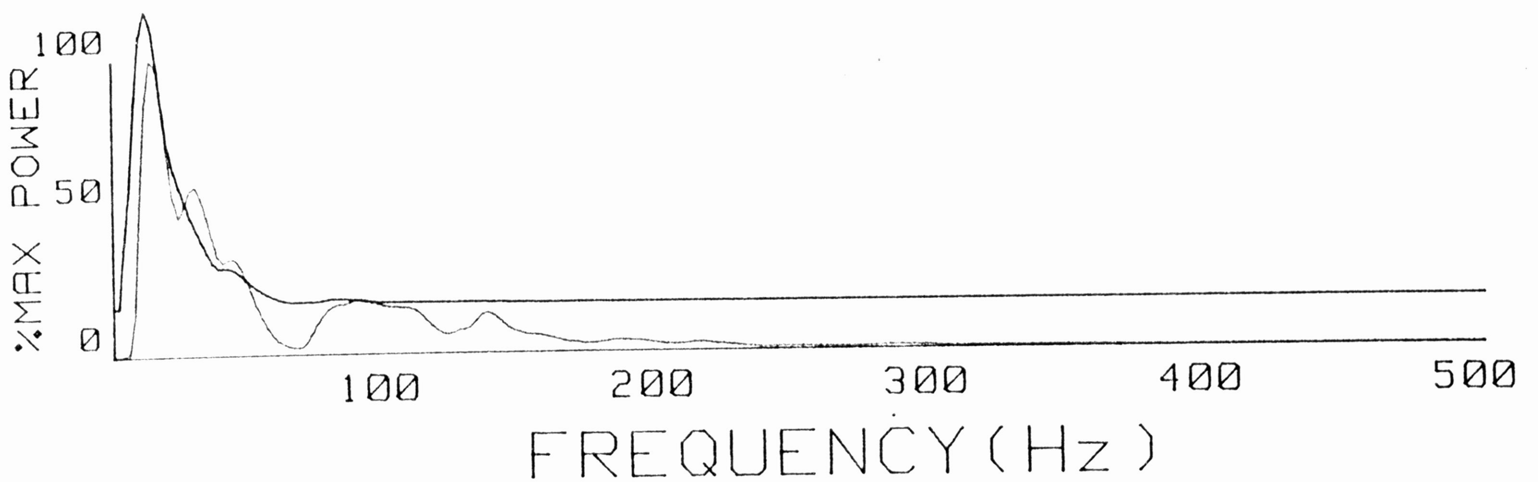
EMG POWER SPECTRA

SUBJECT:EB (INITIAL)

TIME	MPF
0.00	66.71
3.00	61.64
6.00	63.85
9.00	43.43
12.00	39.80
15.00	31.98
18.00	22.67

SLOPE OF MPF -> -2.80
INTERCEPT OF MPF -> 73.30



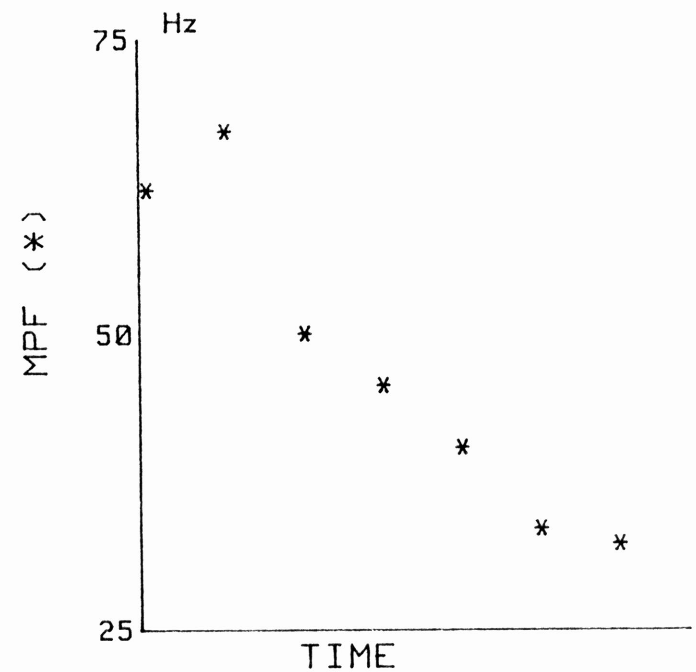


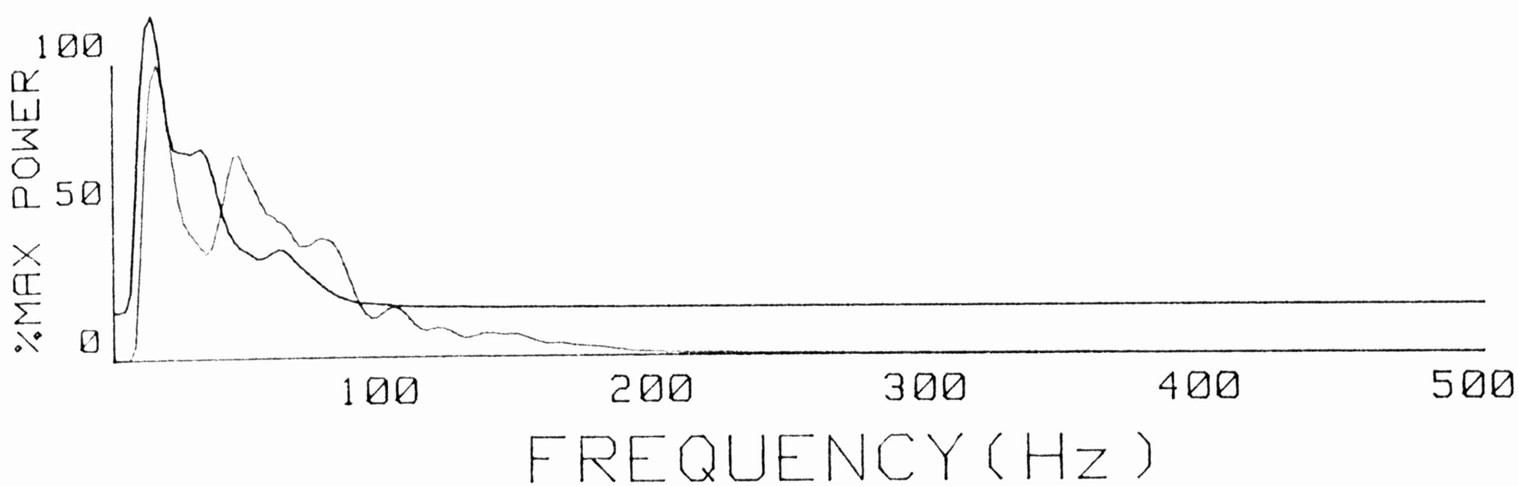
EMG POWER SPECTRA

SUBJECT:EB (FINAL)

TIME	MPF
0.00	60.77
3.00	65.72
6.00	48.59
9.00	44.23
12.00	38.96
15.00	32.06
18.00	30.79

SLOPE OF MPF -> -2.19
INTERCEPT OF MPF -> 66.34



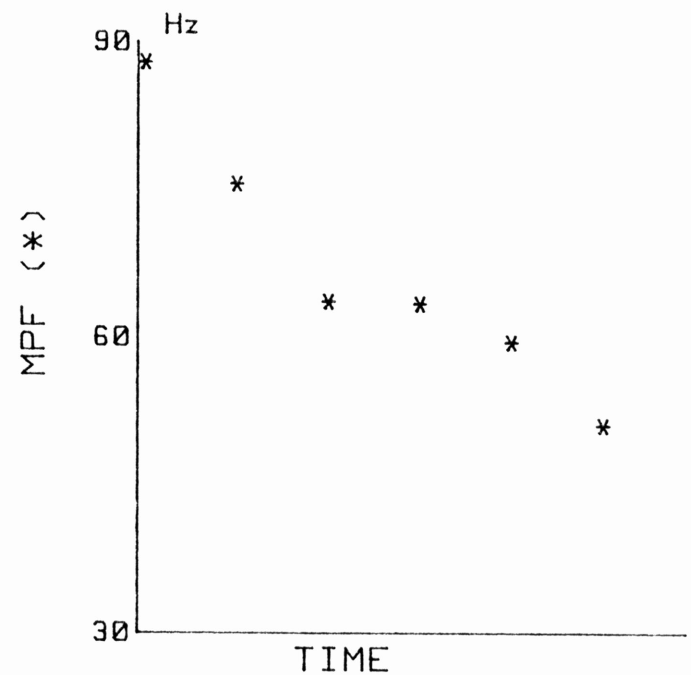


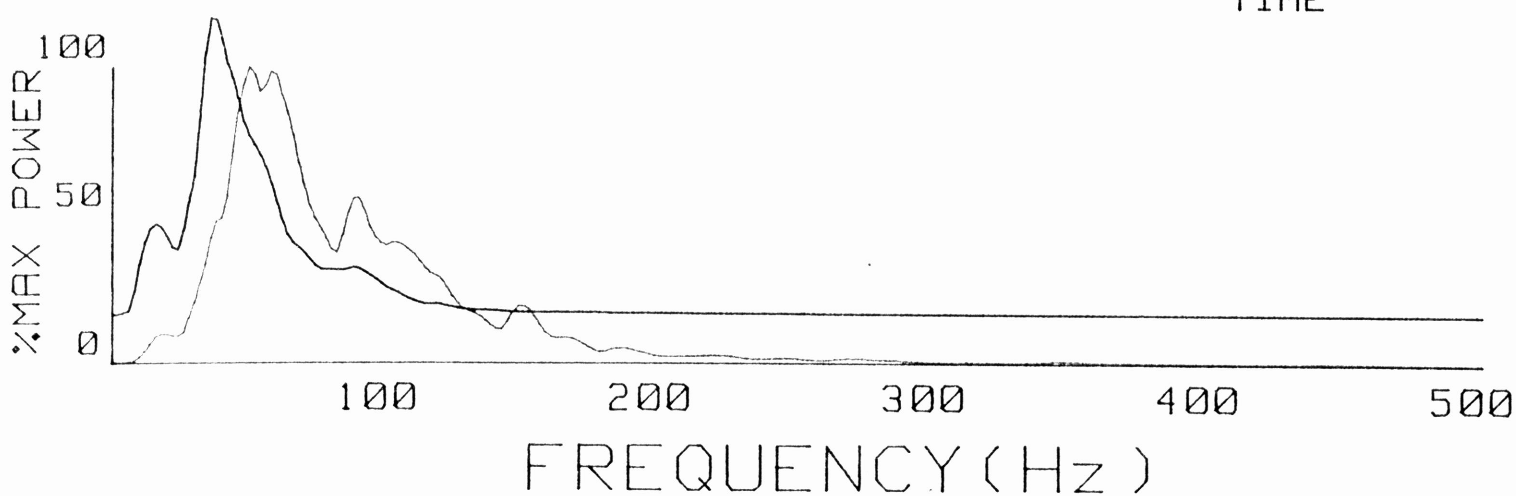
EMG POWER SPECTRA

SUBJECT:GS (INITIAL)

TIME	MPF
0.00	86.12
3.00	73.77
6.00	61.82
9.00	61.59
12.00	57.67
15.00	49.26

SLOPE OF MPF -> -1.77
INTERCEPT OF MPF -> 76.77



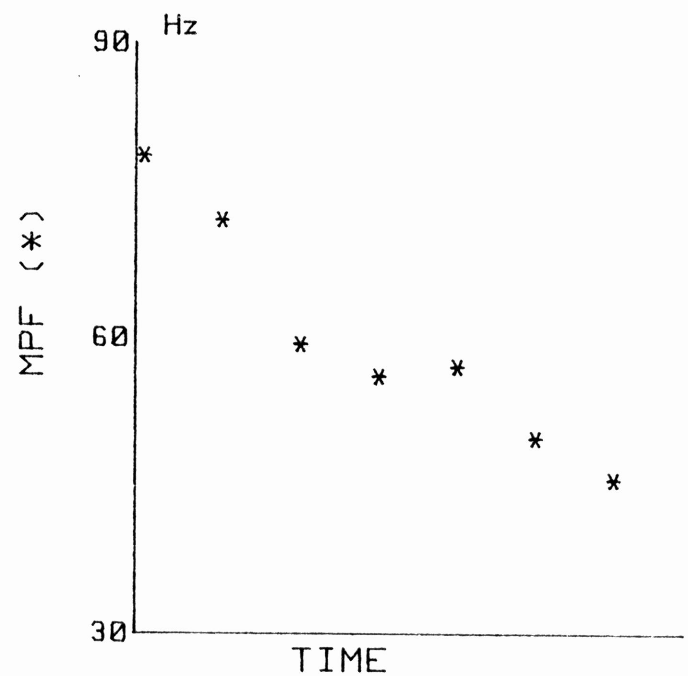


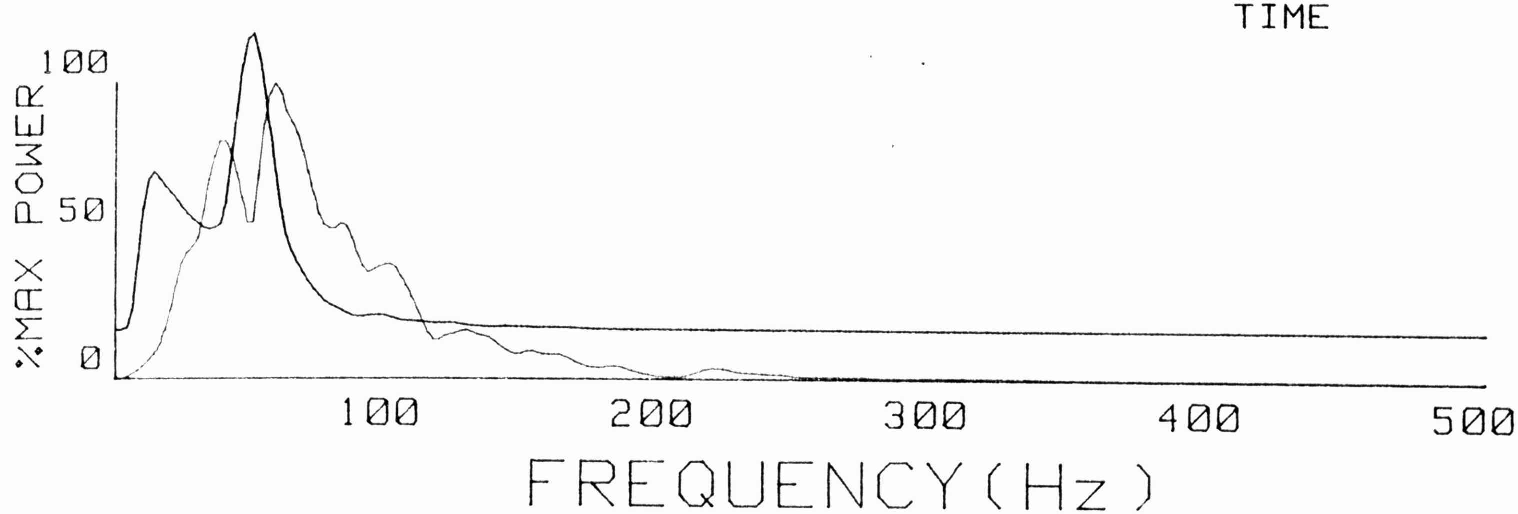
EMG POWER SPECTRA

SUBJECT:GS (FINAL)

TIME	MPF
0.00	76.75
3.00	70.22
6.00	57.59
9.00	54.35
12.00	55.33
15.00	48.08
18.00	43.82

SLOPE OF MPF -> -1.52
INTERCEPT OF MPF -> 70.85



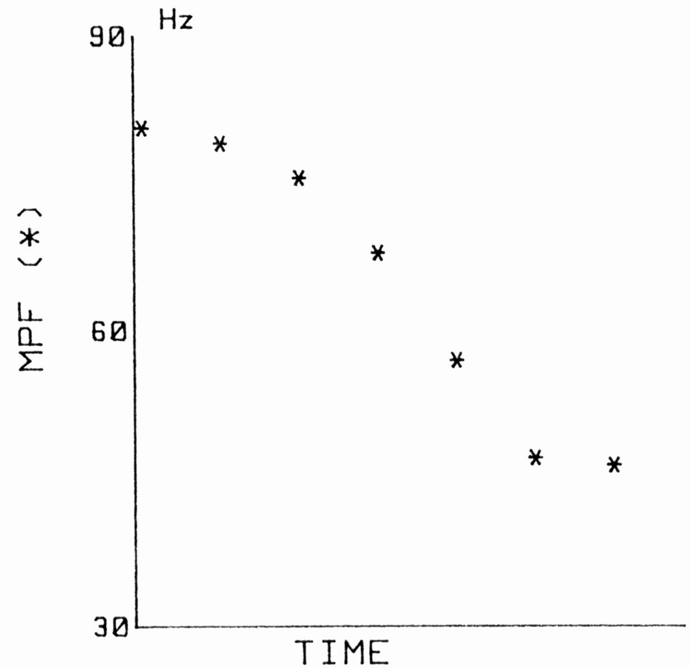


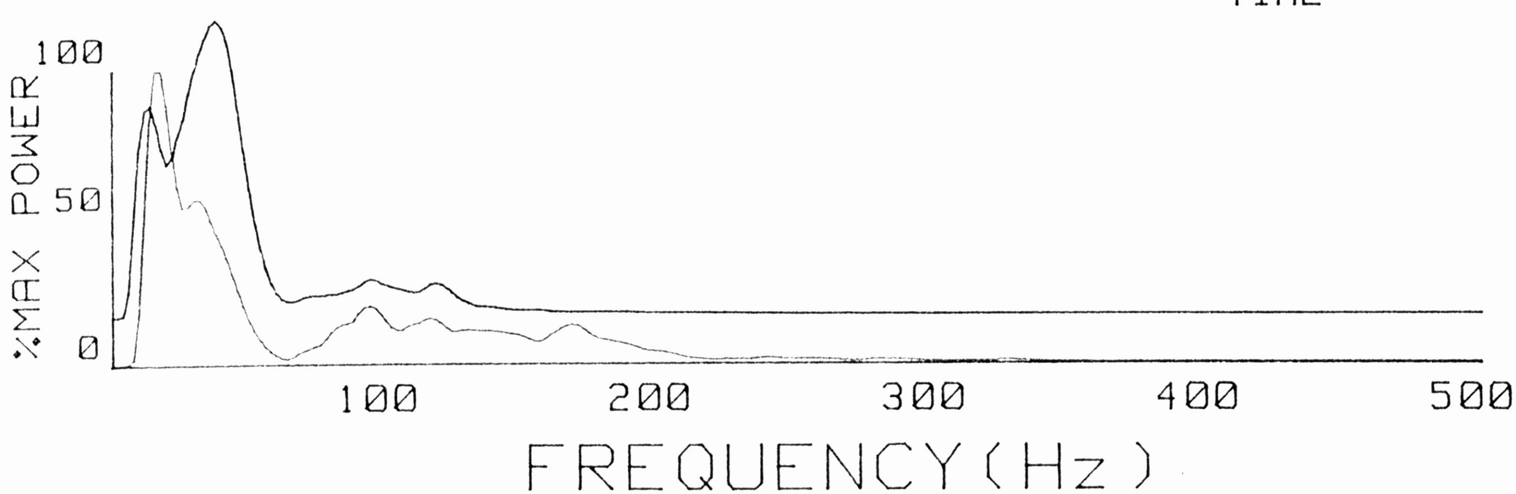
EMG POWER SPECTRA

SUBJECT:BM (INITIAL)

TIME	MPF
0.00	78.83
3.00	77.26
6.00	73.76
9.00	66.11
12.00	55.20
15.00	45.29
18.00	44.53

SLOPE OF MPF -> -2.48
INTERCEPT OF MPF -> 86.36



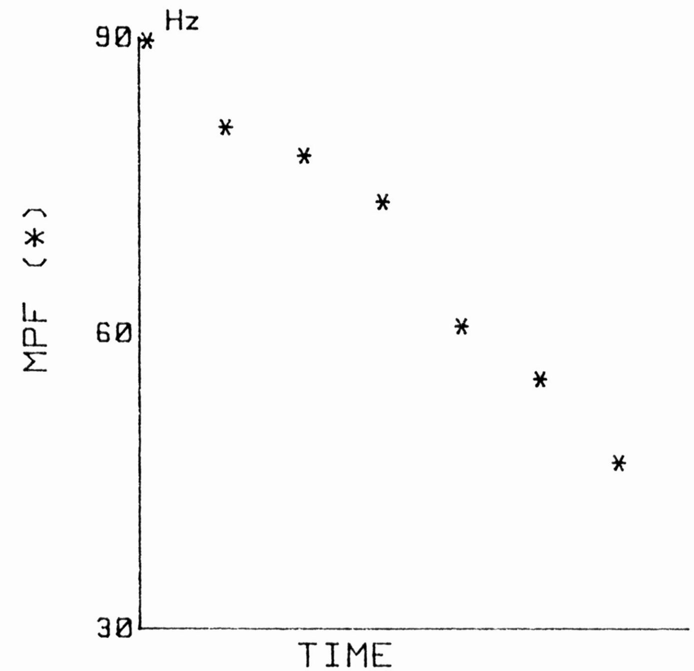


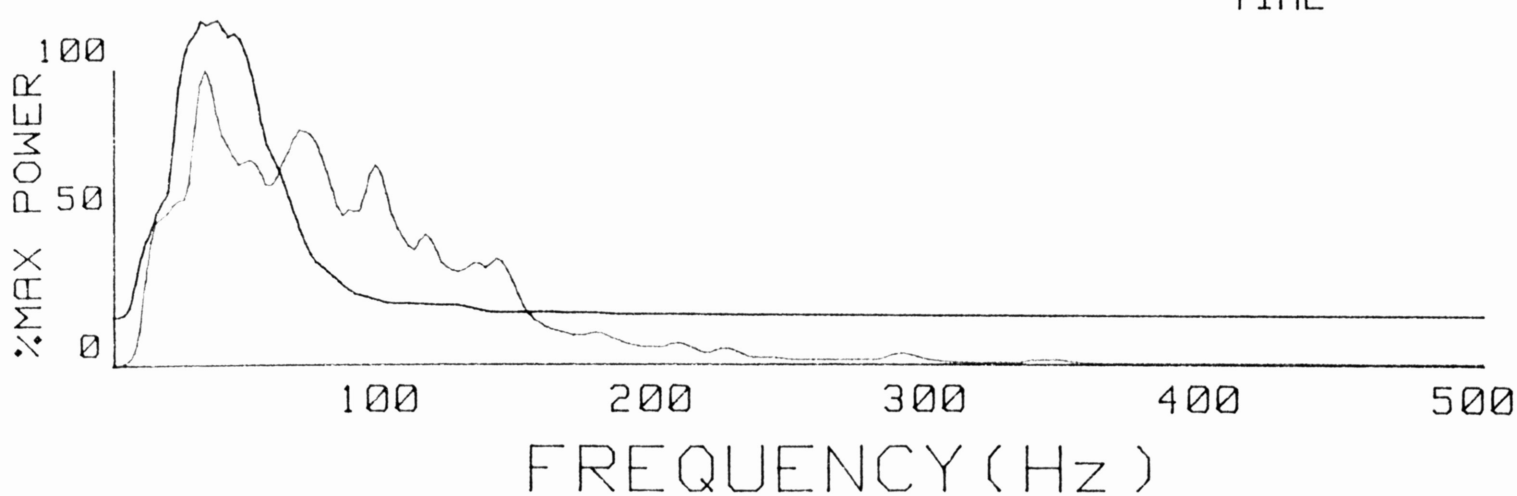
EMG POWER SPECTRA

SUBJECT:BM (FINAL)

TIME	MPF
0.00	87.85
3.00	79.09
6.00	76.21
9.00	71.51
12.00	58.89
15.00	53.54
18.00	45.03

SLOPE OF MPF -> -2.39
INTERCEPT OF MPF -> 89.14



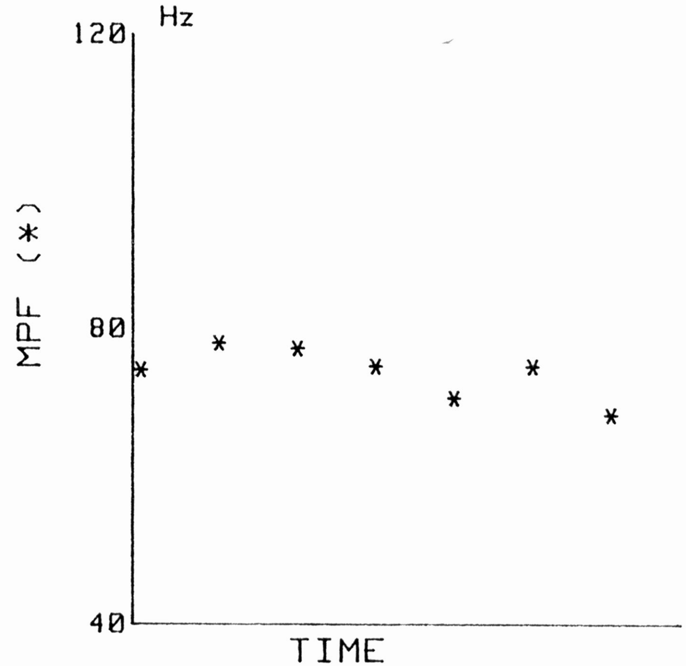


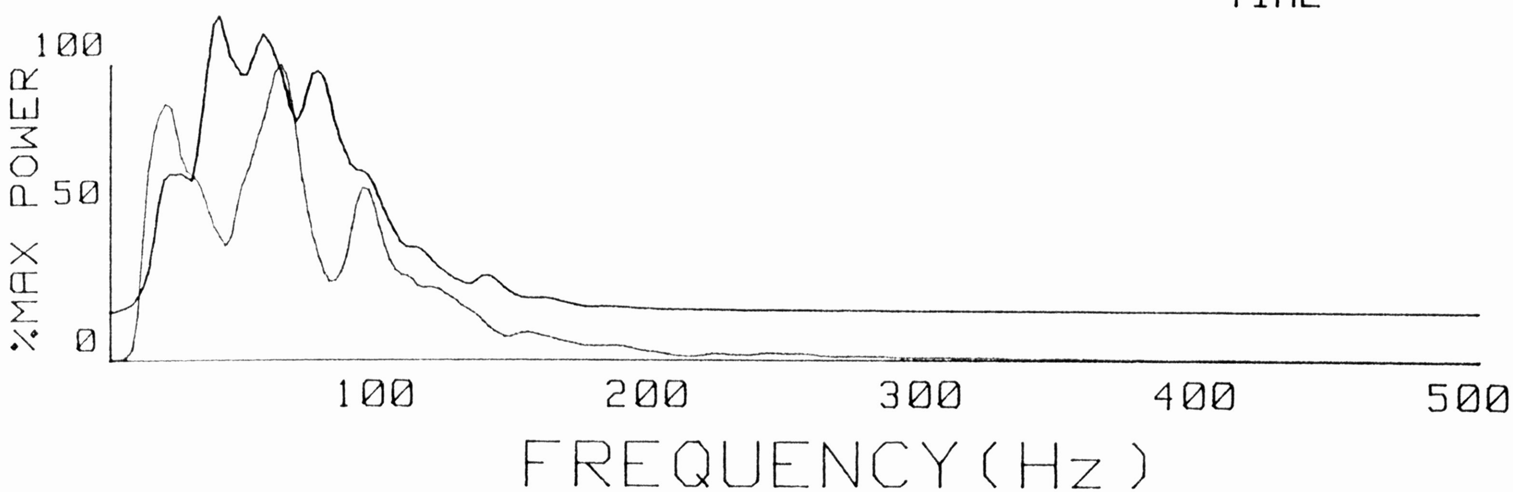
EMG POWER SPECTRA

SUBJECT:JR (INITIAL)

TIME	MPF
0.00	72.00
3.00	75.68
6.00	74.98
9.00	72.58
12.00	68.27
15.00	72.54
18.00	65.95

SLOPE OF MPF -> -0.57
INTERCEPT OF MPF -> 77.69





EMG POWER SPECTRA

SUBJECT:JR (FINAL)

TIME	MPF
0.00	66.97
3.00	66.16
6.00	71.77
9.00	67.88
12.00	68.63
15.00	67.70
18.00	67.47

SLOPE OF MPF -> -0.05
INTERCEPT OF MPF -> 68.76