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# SPECTRAL ANALYSIS OF SKELETAL MUSCLE CHANGES RESULTING FROM 59 DAYS OF WEIGHTLESSNESS IN SKYLAB II

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HOUSTON, TEXAS 77058

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# SPECTRAL ANALYSIS OF SKELETAL MUSCLE CHANGES RESULTING FROM 59 DAYS OF WEIGHTLESSNESS IN SKYLAB II

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16. Abstract

During stressful exercise of the m. gastrocnemius, preflight and postflight surface electromyograms (EMG) were taken from each of the Skylab II astronauts. Measurements on the muscle were made once 5 days before launch, and four times postflight on recovery day, 4 days after recovery 16 days after recovery and 29 days after recovery. It was hypothesized that 1) the disused gastrocnemius would exhibit dysfunction characteristics similar to those found in laboratory studies on disuse and of pathologically atrophied muscle, the characteristics being reduced tension capability and a shifting of the EMG frequency spectrum into higher frequency ranges, and 2) physical stress would be associated with heightened fatigability in the muscle.

Both hypotheses were sustained. The results showed significant shifts of the predominant frequency of the gastrocnemius into higher than normal bands which suggests a relationship between muscle disuse characteristics and pathologic dysfunction characteristics. A reversal of the disuse characteristics commenced, however, within a short period of time after return to earth gravity.

Although the crewmen had daily periods of inflight exercise, the relative disuse of weightlessness significantly increased muscle fatigability. Significant increases in EMG spectral power occurred in the 5 to 80 hertz band and significant decreases occurred in the 80 to 200 hertz band. Such shifts are indicative of muscle fatigue. After four days in earth gravity, considerable spectrum shifting in response to stress was still apparent.

It was concluded that the spectrally analyzed EMG is a sensitive measure of muscle dysfunction that is associated with disuse; antigravity muscles exhibit heightened susceptibility to fatigue when subjected to lengthy weightlessness; and the relationships between heightened excitability and fatigability to other factors such as atrophy, exercise and changes in biochemical constituents which may result from weightlessness should be investigated.

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# SPECTRAL ANALYSIS OF SKELETAL MUSCLE CHANGES RESULTING FROM 59 DAYS OF WEIGHTLESSNESS IN SKYLAB II

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## INTRODUCTION

The Skylab flight program provided an invaluable opportunity to study human muscle function as altered by ideal conditions of long term exposure to full body weightlessness. Considering the accounts of previous research and experience with muscle immobilization, changes in skeletal muscle function resulting from the weightlessness of spaceflight were expected. For example, convalescing patients restricted to bed and immobilized for long periods of time have shown various musculo-skeletal changes including muscular weakness. Specific bedrest research studies have also shown significant changes in musculo-skeletal metabolism (ref. 1).

Electromyography has been used for the study of muscle condition and of muscle fatigue (ref. 2). Initially and even now in some clinics the EMG is evaluated visually by a trained observer who looks at the number of electrically displayed spikes, their height, type and spatial location, and classifies them by an appropriate key. However for experimental purposes and as a result of electronic developments, the integrated EMG came into use. The integration of muscle potentials is an amalgamation of the simultaneous variations of amplitude and frequency into a single measure and a convenient way of collecting muscle electrical data (ref. 3). The principal advantage of the integrated EMG is the convenience of an immediate quantitative readout (ref. 1).

The first useful information produced by the integration technique was from the work of Bigland and Lippold (ref. 4). Since then the integrated EMG has been extensively used for research, especially ergonomics and human factors. Bigland and Lippold showed that a linear relationship exists between the level of muscle activity and strength of voluntary muscle contractions. A number of other studies have since substantiated that finding (refs. 3, 5, 6).

The use of frequency analysis for the evaluation of muscle activity is a more recent technique and provides a unique method for evaluating muscle fatigue. Prior

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*Technology, Inc.

research established the fact that as a specific muscle progressively fatigues, the spectral density shifts from higher frequencies of 40 to 70 Hertz, to lower frequencies of 30 Hertz and less.

Chaffin using surface electrodes found that during isometric and repetitive sequence tension on the biceps in both pathologically symptomatic and asymptomatic individuals, excessive demands on a muscle caused the dominant frequencies to shift toward the lower frequency bands (refs. 7 and 8). Also Chaffin found that in many myopathies the EMG spectrums are shifted toward higher frequencies when compared to asymptomatic individuals. Increased amplitudes were especially pronounced in the 100 to 200 Hertz frequency band. Using needle electrodes Walton (ref. 9) and Gersten, et al, (ref. 10) found, that muscle abnormalities of many forms could be detected by predominant EMG shifts into higher frequency bands.

Chaffin found that EMG amplitude shifts to the lower frequencies were coincidental with subjective muscle discomfort ratings, decreased psychomotor coordination precision, and increased tremor (ref. 11). Chaffin concluded that EMG spectrum data are objective measures of muscle correlated with condition and performance and directly correlated with human performance and behavior.

By means of frequency analysis this study sought to evaluate the EMG functional changes that occurred in a major skeletal muscle as a result of 59 days of relative weightless inactivity in Skylab II. Of interest were the effects of disuse on the neuromuscular system as evidenced by increased excitability and muscle fatigability.

## METHOD

### General

The dependent variable was the muscle action potentials measured by surface electromyographs (EMG) from the gastrocnemius muscle of each of the three crewmen on the Skylab II mission during a stressful exercise of the muscle (fig. 1). Both preflight and postflight measures were recorded. No inflight EMG data were collected. Future reference to the Skylab II crewmen will be by numbers 098, 100, and 101.

### Instrumentation

The instrumentation used to record the EMG signals is shown on fig. 2. The gain of the Model 3640 Burr-Brown Preamplifier was fixed at 300. The gain of the Model 13-4215-32 Brush Preamplifier was varied to obtain an optimal signal level for the Model FR-1260 Ampex Tape Recorder. The data were recorded in the FM mode at a tape speed of 3 3/4 inches per second (ips).

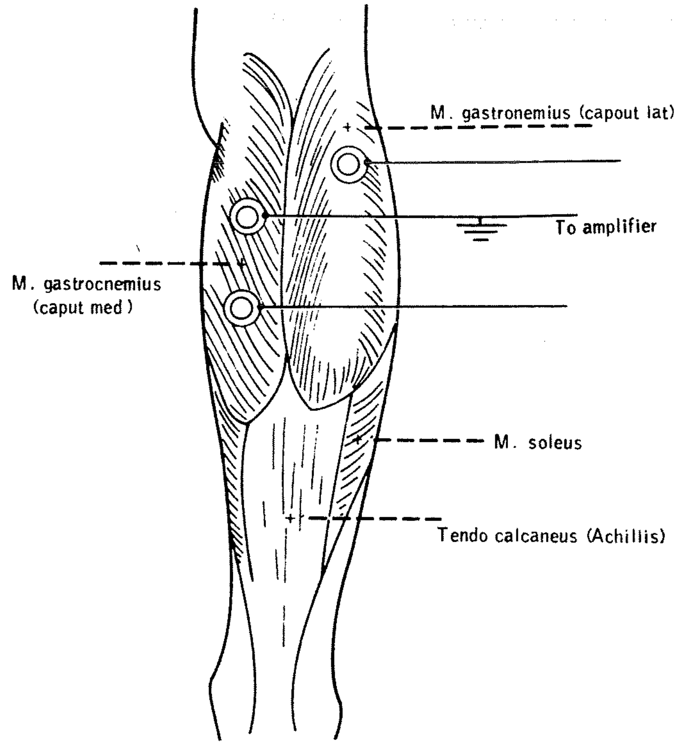

Figure 1.- The gastrocnemius muscle.

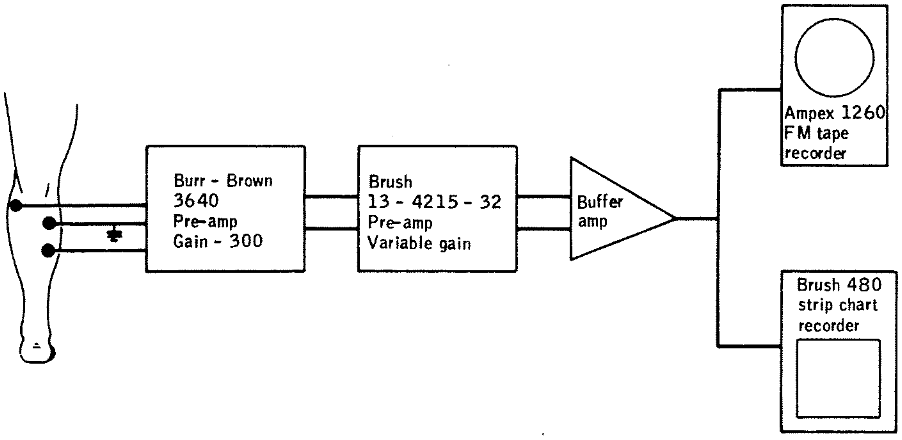

Figure 2.- Diagram of instrumentation.

## EMG Recording

The EMG data were taken once preflight at F-5 days, and four times postflight at R+0, R+4, R+16 and R+29 days. Three surface electrodes were placed on the gastrocnemius muscle of the right leg. One electrode served as ground while the other two electrodes were used to detect the differential EMG signal. The exact positions of the electrodes varied somewhat from subject to subject but were typically located as shown on fig. 1.

## Procedure

Measurements were made with the gastrocnemius stressed at two different levels. The first stress level, referred to as the 0 pounds test, consisted of the subject balancing himself on the ball of the right foot. The second stress level, the 40 pounds test, required the subject to balance solely on the ball of his right foot while holding a 40 pound weight at the approximate vicinity of the upper right rectus femorus. During the F-5 sessions, the duration of each stress level was 10 seconds in length. Postflight, the duration of each stress lasted 20 to 25 seconds. There was an approximate 30 second pause between the first and second stresses. Table I shows the EMG data collection format with nomenclature for individual measurements.

TABLE I.- EMG DATA FORMAT

| Test | Muscle stress | Preflight | Postflight | | |
|---|---|---|---|---|---|
| | | F-5 | R+0 | R+4 | R+29 |
| First | 0 pounds (1st 10 sec) | F-5/0# | R+0/0# (1st) | R+4/0# (1st) | R+29/0# (1st) |
| | 0 pounds (last 10 sec) | - | R+0/0# (last) | R+4/0# (last) | R+29/0# (last) |
| Second | 40 pounds (1st 10 sec) | F-5/40# | R+0/40# (1st) | R+4/40# (1st) | R+29/40# (1st) |
| | 40 pounds (last 10 sec) | - | R+0/40# (last) | R+4/40# (last) | R+29/40# (last) |

Note: On F-5, only 10 seconds of data were collected on each test.

## Treatment of EMG Data

The EMG data were analyzed by a power spectral density analysis program on the 1108 Univac. The analog data were digitized at 2000 samples per second sps to provide a computer compatible tape and 10 seconds data were segments selected for analysis at the beginning and end of each of the 0 pound and 40 pounds test conditions of the subject doing a toe stand. A 5 hertz high pass filter was used to eliminate the effects of baseline excursions. A 60 hertz digital notch filter was used to abrogate the effects of 60 hertz noise in the data. The cutoff frequency for the data analysis was 400 hertz. The computed bandwidths were 20 hertz, which resulted in a data printout for each 10 hertz bandwidth from 0 to 400 hertz.

So different sets of data could be compared to establish a standardized measurement, the power of a particular frequency band was computed as a percentage of the power in the bandwidth containing the maximum amplitude or power.

## RESULTS

Several figures are presented to show the results of the spectral density analysis of the Skylab II EMG data.

Figure 3 is a plot of EMG data that were averaged across the three crewmen that shows the effects of prolonged weightlessness on the location of the predominant EMG frequency band of the gastrocnemius muscle, and the reacclimation of the muscle to earth gravity. The 0#(1st) data for each day were used to construct the data plot (Table I). After 59 days in the weightless state, the averaged predominant frequency of the gastrocnemius muscle shifted from the preflight baselined 55 hertz band to the 95 hertz band. However, after 4 days in earth gravity, the averaged predominant frequency shifted back to the 75 hertz band. By the end of 29 days frequency was back within the F-5 preflight baseline.

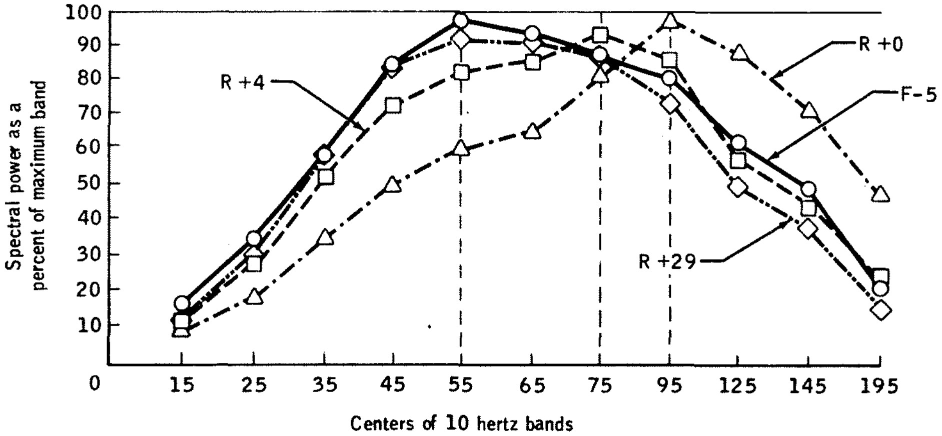

Figure 3.- Plot of EMG data averaged across three crewmen on the initial 0 pound test on F-5, R+0, R+4, and R+29.

Figures 4, 5 and 6 show the corresponding data plots for the individual crewmen. Crewman 098 (fig. 4) exhibited the largest frequency shift, from 55 to 125 hertz. However, after four days in earth gravity his predominant EMG frequency had shifted back to 75 hertz and by 29 days was back to baseline.

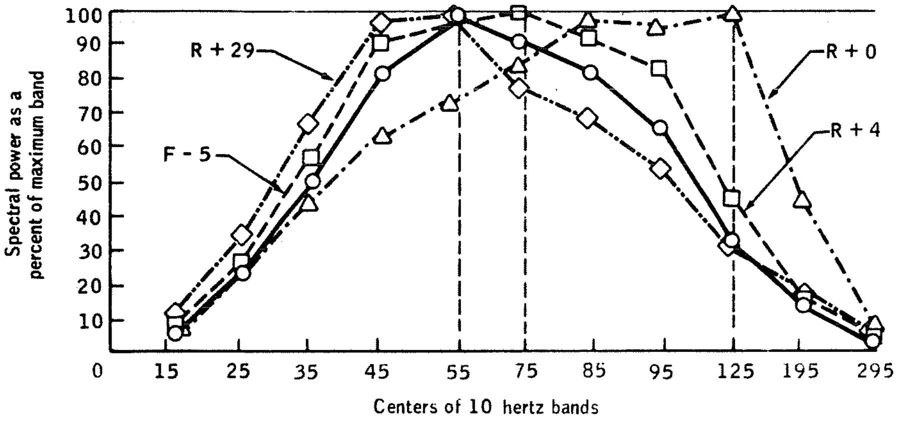

Figure 4.- Plot of EMG data from crewman 098 on initial 0 pound test on days F-5, R+0, R+4, and R+29.

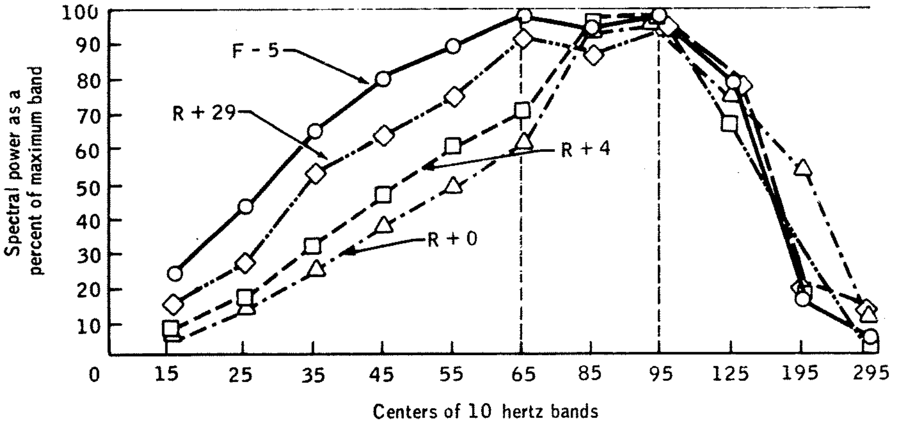

Figure 5.- Plot of EMG data from crewman 100 on initial 0 pound test on days F-5, R+0, R+4, and R+29.

Crewman 100 (fig. 5) exhibited a different effect pattern. His R+0 days data show a shift in predominant frequency to 95 hertz from the baselined 65 hertz. For measurements following on R+4 and R+29 days, his predominant frequency did not change though there were substantial spectral power increases in the lower frequencies.

The R+0 data from Crewman 101 were not good. The extent of shift in his predominant frequency is unknown. However, his R+4 data (fig. 6) peaked at the same frequency as did crewman 098 and by R+29 days, his predominant frequency was back to baseline.

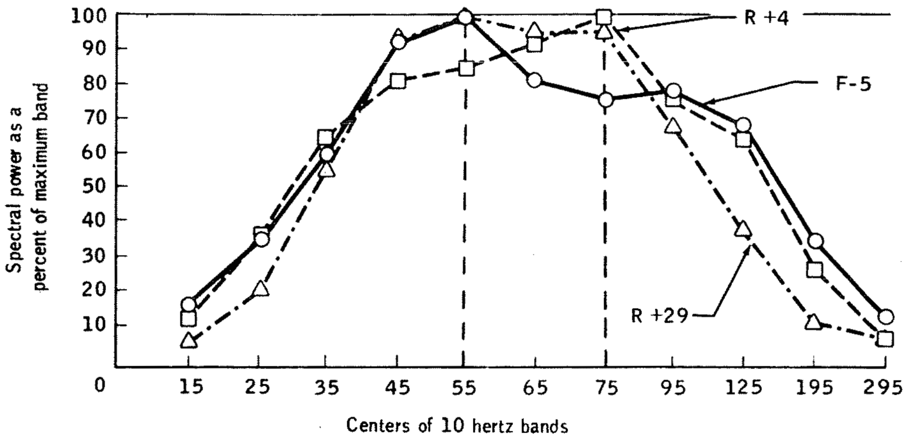

Figure 6.- Plot of EMG data from crewman 101 on initial 0 pound test on days F-5, R+4, and R+29.

To determine the relative effects of weightlessness on the response of the gastrocnemius muscle on R+0 days prior to the programmed muscle stress, the [R+0/0#(1st) - F-5/0#] difference measure was computed for each of the crewmen and averaged. The results are shown on fig. 7. Generally, on R+0 days the

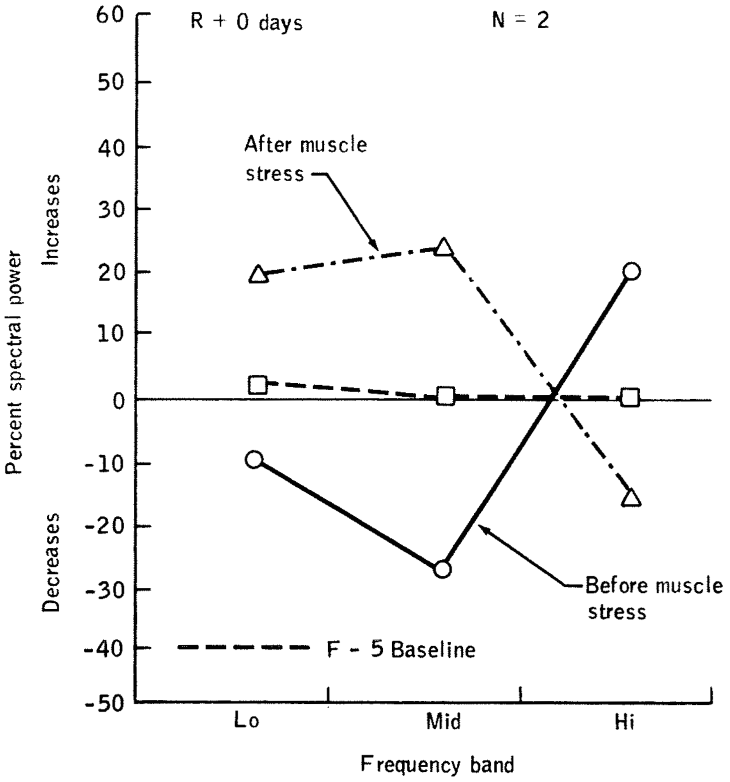

Figure 7.- Effects of zero g and muscle stress on the gastrocnemius on R+0 days.

crewmen showed moderate to large decreases in the lower frequencies, and large increases in the higher frequencies. The "LO", "MID", and "HI" frequency ranges were defined as 5 to 30, 30 to 80, and 80 to 200 hertz, respectively. Spectral power shifting down in the LO and MID frequencies and up in the HI frequencies is evident.

Also on fig. 7 are the results of the muscle stress tests which included both the 0 pounds test and the 40 pounds test. These data include the [R+0/40#(last) - R+0/0#(1st)] differences averaged for the crewman group. The "after muscle stress" data showed a considerable reversal of effect when compared with the initial postflight data. The lower frequencies showed moderate to large increases of power. The higher frequencies showed large decreases of power. These changes are significant when compared with the F-5 baseline measurements, the test procedures being comparable except for a shorter duration during preflight testing.

Figures 8 and 9 show the residual effects of weightlessness on R+4 days and R+29 days as well as the effects of muscle stress testing. Four days after return to earth's gravity, the residual effect of weightlessness had practically vanished but the effects of muscle stress were still evident in the lower frequencies. Most residual effects had disappeared by R+29 days.

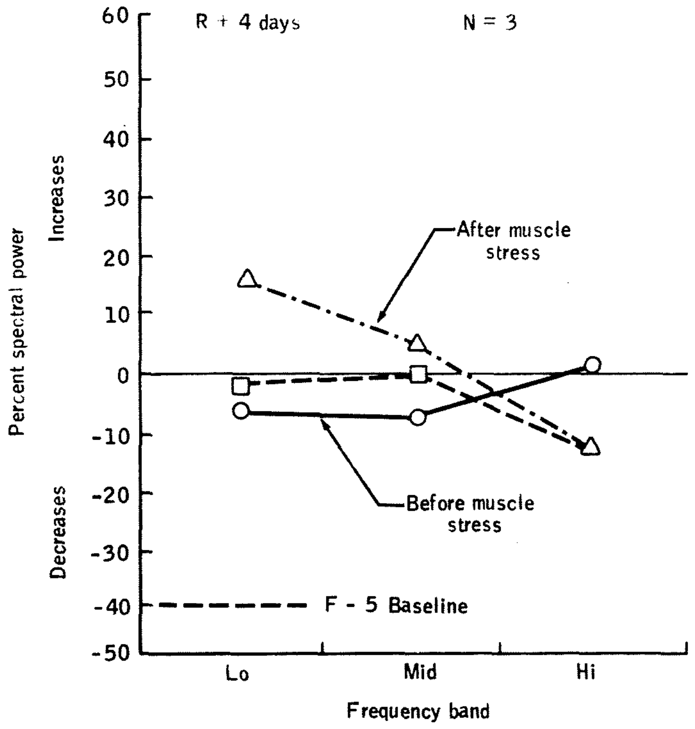

Figure 8.- Residual effects of zero g and muscle stress on the power density spectrum of the gastrocnemius.

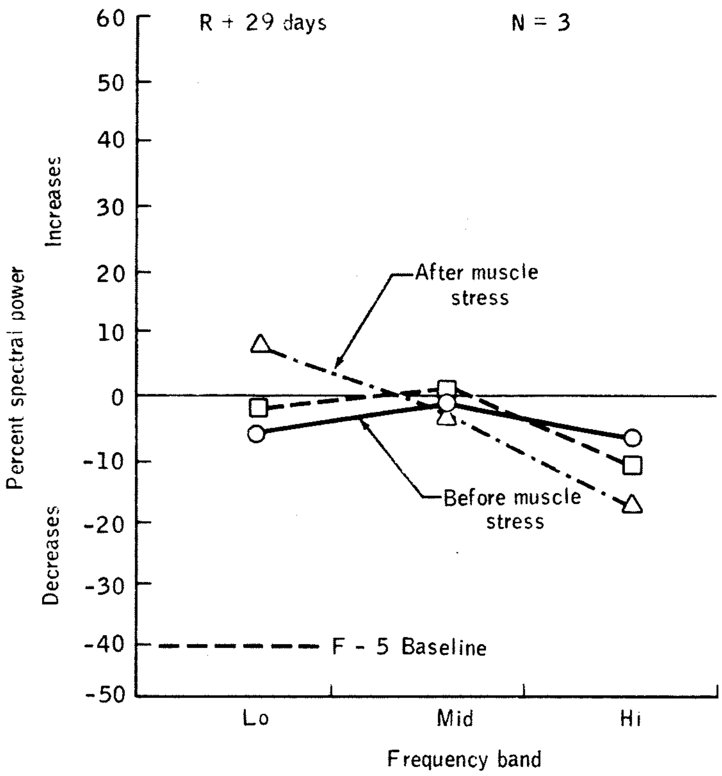

Figure 9.- Residual effects on R+29.

Figures 10, 11, 12, 13, 14, and 15 show the weightlessness and muscle stress effects on individual crewmen. Crewman 101 data are not shown because the R+0 days data were not good. Differences in individual responses are observable. On R+0 days (fig. 10), the weightlessness effect on the muscles of crewman 098 was most pronounced in the higher frequencies. Crewman 100 showed little response in the HI range but considerable response in the lower frequencies. Again, for each crewman the reacclimation of the gastrocnemius muscle to earth gravity was evident with the concomitant decreases in the effects of muscle stress. In his response to the muscle stress test crewman 100 exhibited a slower reacclimation, which is shown at R+29 days. At R+0 and R+4 days, crewman 100 responded mostly in the lower frequencies. At R+29, (fig. 15) he showed a considerable shift of predominant frequency towards the lower frequencies and considerable decrease in the EMG amplitudes in the HI frequency range.

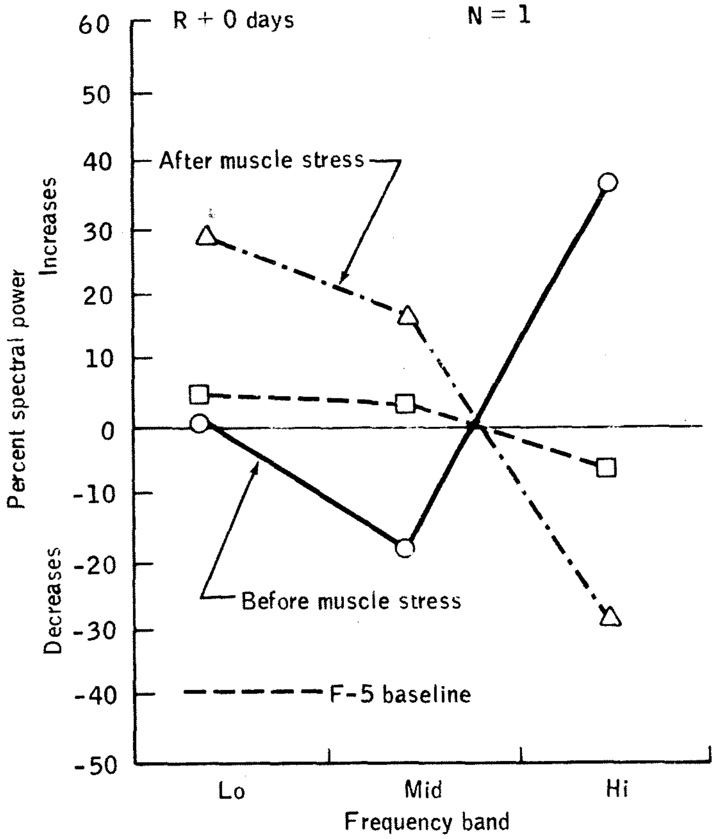

Figure 10.- Zero g and muscle stress effects on power density of the gastrocnemius on R+0 days for crewman 098.

## DISCUSSION

Based on the theoretical considerations generalized from previous research on muscle dysfunction and the phenomenon of muscle fatigue, the results of this study agree closely with hypothesized results. First, it was expected that a skeletal muscle deconditioned by prolonged weightlessness would exhibit certain dysfunction characteristics, such as the shifting of the EMG spectrum into the higher frequency ranges, similar to the clinically atrophied muscle (refs. 7, 9, 10). And second, it was expected that the muscle's response to physical stress would be a shifting of the spectrum toward the lower frequencies as demonstrated by physically fatigued muscles (refs. 8, 11, 12, 14). By the results of this study both expectations were supported. Tables II and III show comparisons between the expected and observed spectral characteristics of the crewmen's gastrocnemius EMG on recovery day. The "observed" values correspond to the values plotted on figs. 9, 10, 11, 12, 13, and 14.

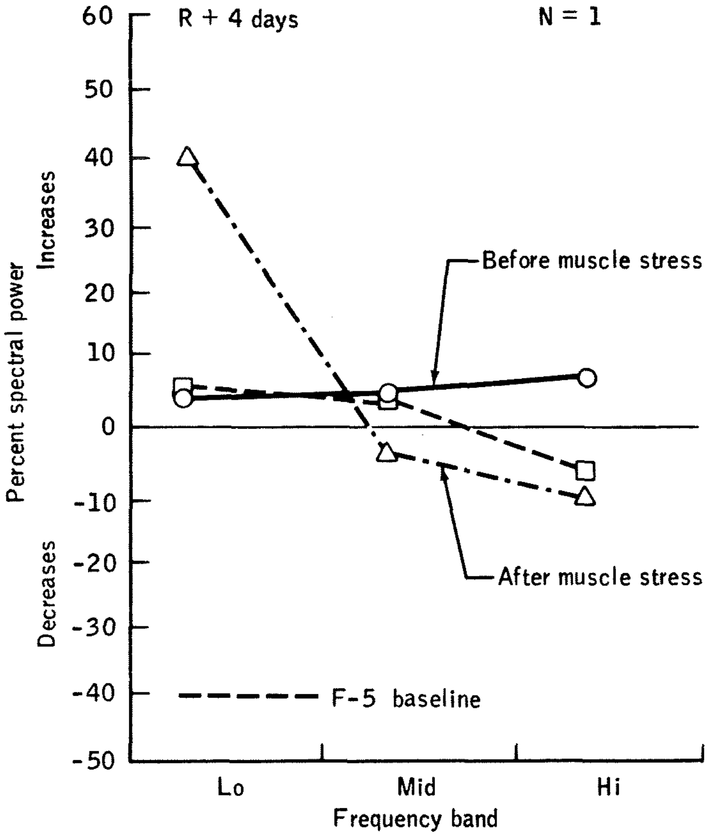

Figure 11.- Zero g and muscle stress effects on R+4 days for crewman 098.

The shifting in the EMG power spectrum of the crewmen's gastrocnemius muscle into higher frequency bands after 59 days in space exhibits symptomatic characteristics comparable to the neuro-pathologic muscle. Figure 16 depicts a comparison of the EMG spectrum of a dystrophic muscle to that of a spaceflight muscle after 59 days of weightlessness (ref. 7). Shifts from the normal predominant frequency were comparable for both muscles. Thus, frequency analysis of the EMG of the weightlessness deconditioned muscle suggests a relationship between the characteristics of the deconditioned muscle and the dysfunction characteristics of a pathologic muscle.

The effects of the spaceflight deconditioning of Skylab II were reversible and a return to normal commenced within a short time after the crewmen returned to the earth gravity. However, each crewman differed in his rate of reacclimation to normal gravity. For example, crewman 100 reacclimated more slowly than the other two. This is shown on figs. 13, 14, and 15. Even on R+29 days (fig. 15), the residual effects of weightlessness prior to muscle stress were still apparent. The effects of the muscle stress test were even more pronounced. Significant shifting in EMG response to the stress occurred in the LO and HI frequencies, which suggests a continued heightened susceptibility to fatigue. This lingering condition in crewman 100 may be attributable to a minimum of postflight interpolated exercise that was beneficial to the gastrocnemius. If this suggestion is correct, it emphasizes the importance of interpolated exercise in the recovery of spaceflight deconditioned muscles.

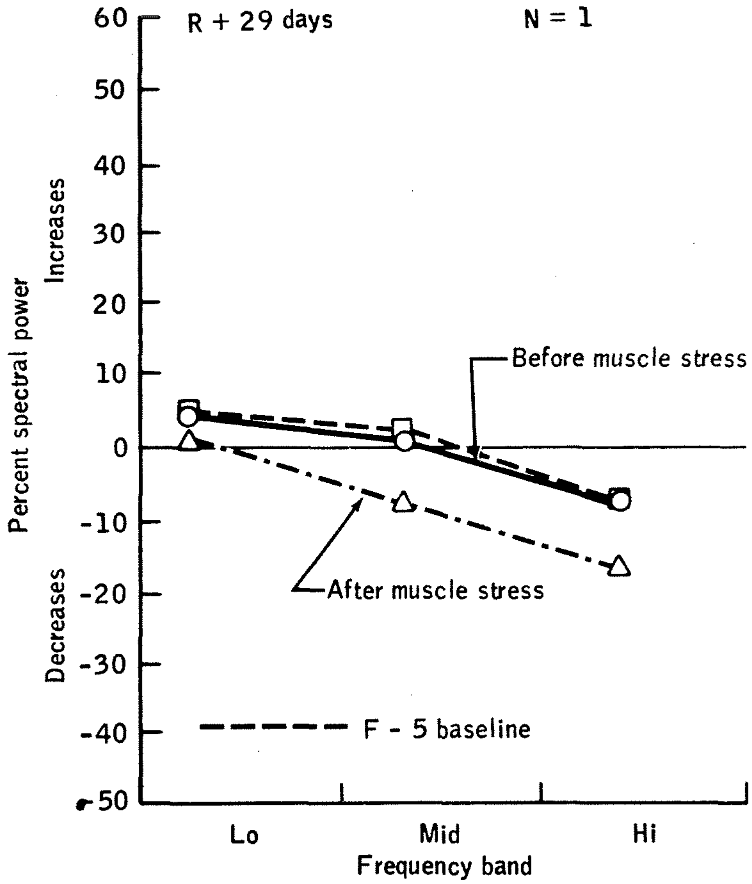

Figure 12.- Residual effects on R+29 for crewman 098.

That prolonged exposure to weightlessness increased muscle fatigability is readily apparent (figs. 7 and 15). "Before stress" and "after stress" levels in the lower frequencies were changed considerably from the earth gravity baseline; shifts from "before" to "after" were more evident. It is important to note that large spectral shifts resulted from a relatively short 40 to 50 second period of submaximal muscle stress. The spectrum shifts are more pronounced on figs. 17 and 18, which show considerable shifting toward the lower frequencies for 10 seconds EMG measurements taken 10 seconds apart during the 40 pounds test. Considerable shifting of the spectrum was still apparent after four days of reacclimation (fig. 18).

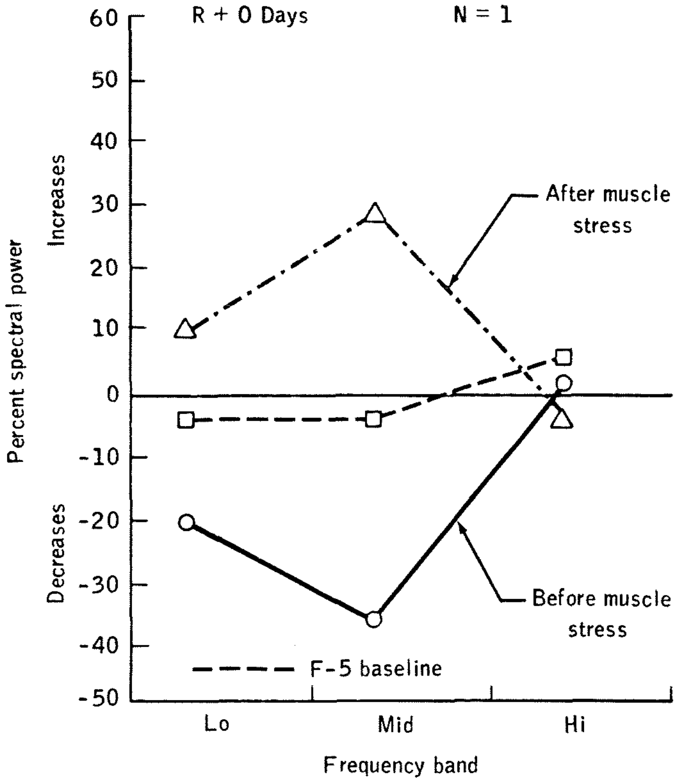

Figure 13.- Zero g and muscle stress effects on power density of the gastrocnemius on R+0 days for crewman 100.

It may be argued that the observed power spectrum shifts are simply muscle reconditioning responses and say nothing about a heightened fatigability. However, the immediacy and extent of the spectral power shifts into lower frequencies resulting from muscle stress, and the fact that the initial response of the muscle on a subsequent measurement day of R+4 is shifted back toward the initial response of the preceding R+0 measurement day suggests a heightened fatigability of the muscle. On the subsequent measurement day of R+4 there is a recovery, so to speak, from the effects of the fatigue inducing stress of the preceding R+0 measurement day. It would be useful to know the residual effects, if there are any, from interim measurement period of less than 4 days to see how recovery is slowed or changed during the shorter interim period.

Concerning the EMG spectrum shifts, there appears to be two things that can occur that suggests the possibility of two different although related components to EMG spectrum phenomena: a shifting of the predominant frequency coincidental with the increases and decreases in spectral power in appropriate frequency bands; and, increases and decreases in frequency bands without concomitant shift in predominant frequency. For example, crewman 098 exhibited the shift type of response and crewman 100 showed the broad spectrum type. Walton found evidence for two types of EMG spectra shifts in his investigation of EMG frequency characteristics of some of the common myopathies and neuropathies (ref. 9). Although the reported frequency changes herein do not approach the magnitude of the changes reported by Walton, they do correspond closely to the magnitude of changes found in pathologic muscles by Chaffin (ref. 7), (fig. 16).

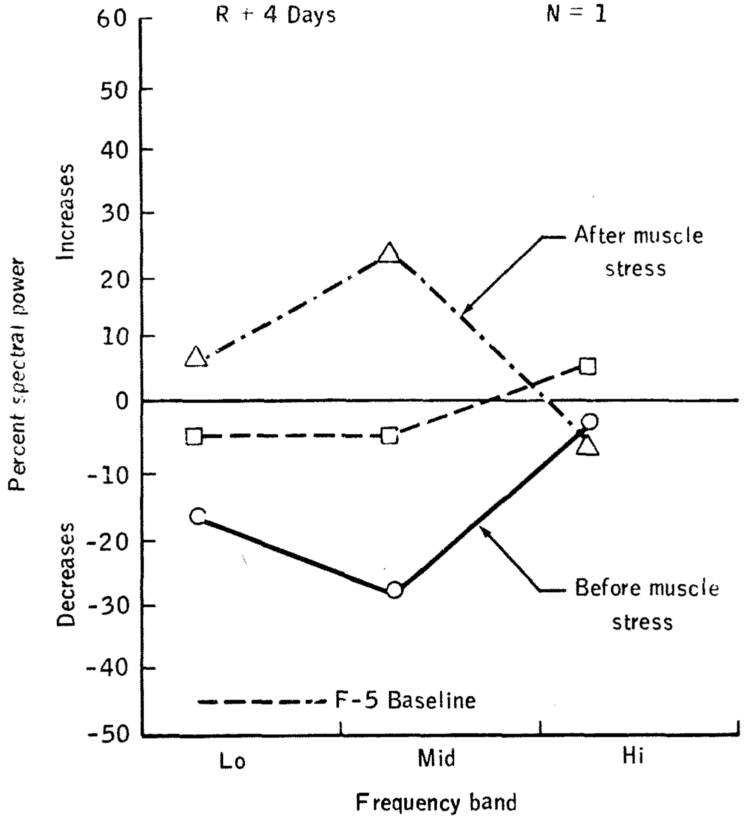

Figure 14.- Residual effects on R+4 days for crewman 100.

For crewman 100, R+29 days testing showed a considerable shift in the predominant frequency toward the lower frequencies with a large decrease in EMG spectral power in the higher frequencies (fig. 15). No subsequent measurements were taken, however, and it is not known how the time course affected the subsequent residual baseline and predominant frequency location. Perhaps the crewman's neuromuscular response to stress at R+29 days was an indication that muscle reconditioning had progressed sufficiently to reflect the expected downward shift in the predominant frequency location. Unfortunately, this experiment does not provide enough data to support a more definitive suggestion regarding shifts of frequency.

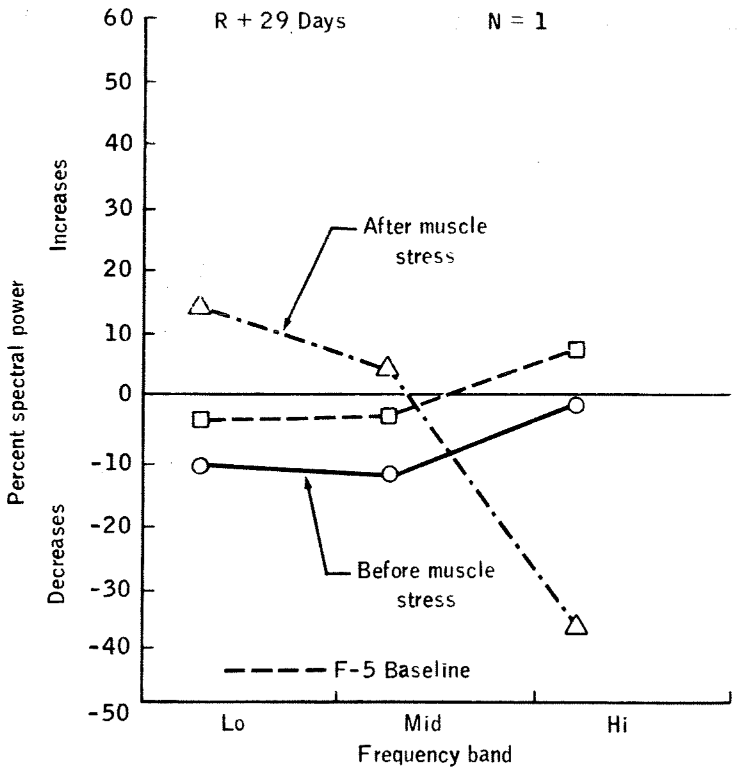

Figure 15.- Residual effects on R+29 for crewman 100.

TABLE II.- COMPARISON OF EXPECTED EMG POWER SPECTRUM SHIFTS TO OBSERVED EMG POWER SPECTRUM SHIFTS ON R+0 DAYS FOR CREWMAN 098

| Frequency bands | Baseline after stress |  | R+0 after stress |  | R+0 before stress |  |
|---|---|---|---|---|---|---|
|  | Expected | Observed | Expected | Observed | Expected | Observed |
| 5 – 30 | Small increases | Small increases | Moderate increases | Large increases | Moderate Decreases | Small increases |
| 30 – 80 | Small to moderate increases | Small increases | Moderate to large increases | Moderate increases | Moderate to large decreases | Moderate to large decreases |
| 80 – 200 | Small to moderate decreases | Small decreases | Moderate to large decreases | Large decreases | Moderate to large increases | Large increases |

TABLE III.- COMPARISON OF EXPECTED EMG POWER SPECTRUM SHIFTS TO OBSERVED EMG POWER SPECTRUM SHIFTS ON R+0 DAYS FOR CREWMAN 100

| Frequency bands | Baseline after stress | | R+0 After stress | | R+0 before stress | |
|---|---|---|---|---|---|---|
| | Expected | Observed | Expected | Observed | Expected | Observed |
| 5 – 30 | Small increases | Small decreases | Moderate increases | Moderate increases | Moderate decreases | Moderate to large decreases |
| 30 – 80 | Small to moderate increases | Small decreases | Moderate to large increases | Large increases | Moderate to large decreases | Large decreases |
| 80 – 200 | Small to moderate decreases | Small increases | Moderate to large decreases | Small decreases | Moderate to large increases | Small increases |

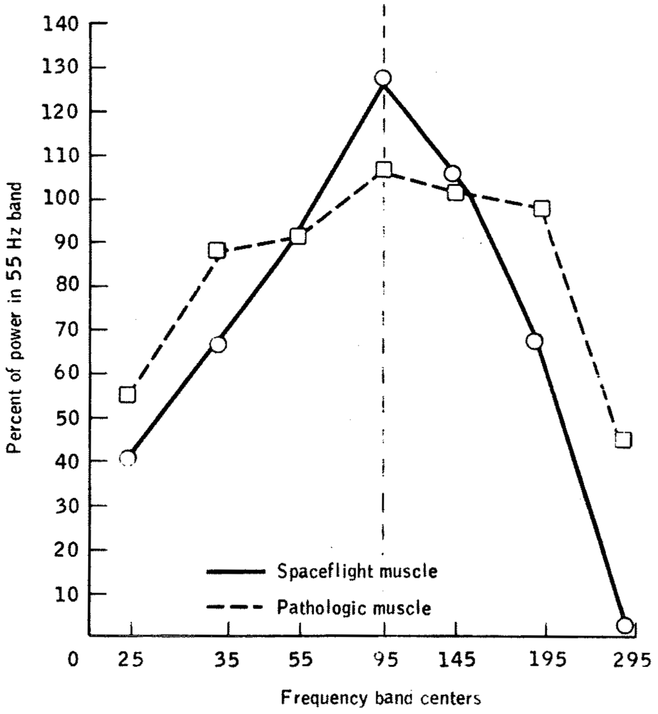

Figure 16.- Comparison of data from muscle after space flight to pathologic muscle.

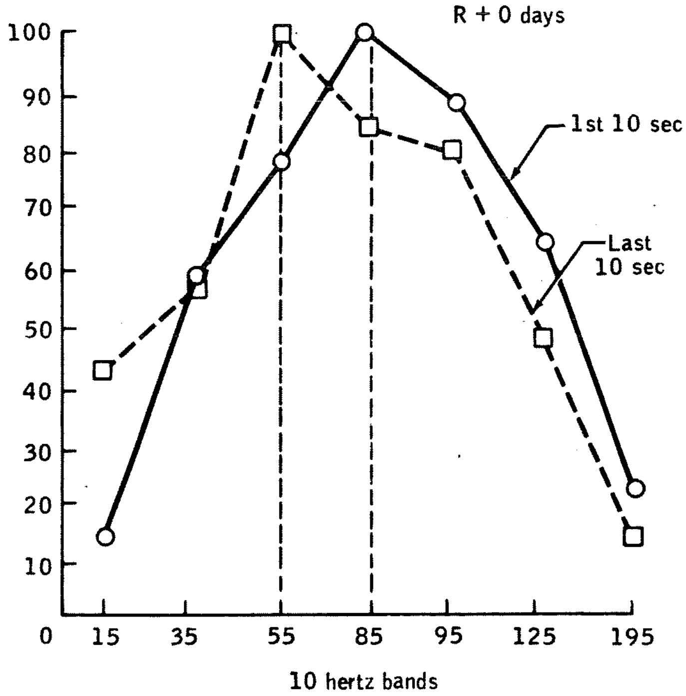

Figure 17.- Comparison of first and last 10 seconds of 40 pound test on R+0 for crewman 098.

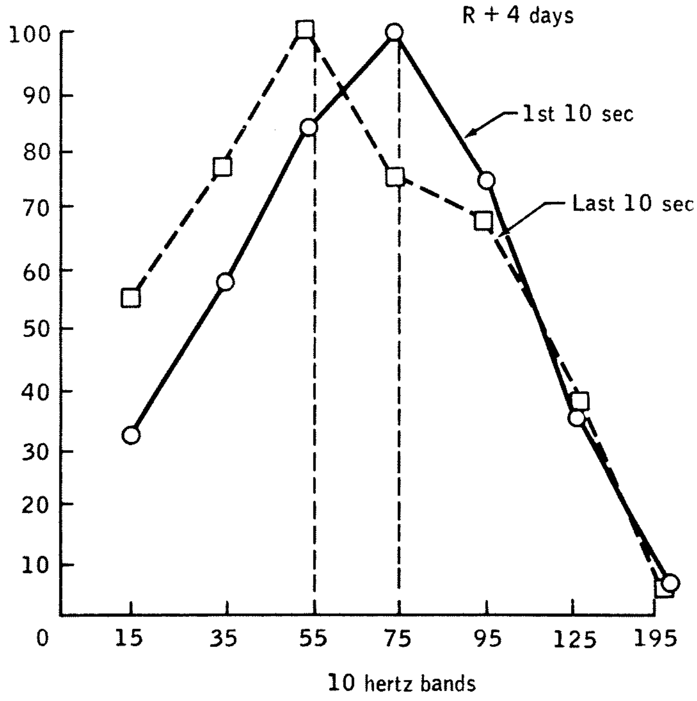

Figure 18.- Comparison of first and last 10 seconds of 40 pound test on R+4 for crewman 098.

# CONCLUSIONS

The following suggested conclusions are:

1. The spectrally analyzed EMG is a sensitive measure of the extent of antigravity muscle dysfunction caused by a prolonged period of disuse in weighlessness

2. Antigravity muscles subjected to lengthy weightlessness exhibit heightened susceptibility to fatigue and are susceptible to concomitant psychomotor dysfunction associated with the muscle fatigue status

3. As evidenced by EMG measures, the relationship between muscle dysfunction brought about by weightlessness, and other factors such as extent of muscle atrophy (if any), quantity and quality of exercise, frequency of exercise, and losses in biochemical constituents should be investigated

4. Additional muscle studies under more controlled conditions should be conducted to verify these conclusions

5. Further muscle research should be considered in future spaceflight research planning

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