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G. WRIGHT , D. WASSERMAN , E. POTTALA & F. DUKES-DOBOS

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Contraction strength, endurance and the electromyogram of the biceps brachii were examined following treadmill exercise at 50 and 60% of maximum aerobic capacity. Exercise did not exert a significant influence on any of these parameters indicating they are relatively insensitive indicators of general fatigue.

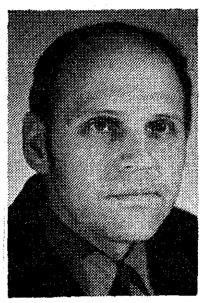
The effect of general fatigue on isometric strength-endurance measurements and the electromyogram of the biceps brachii

G. WRIGHT, D. WASSERMAN, E. POTTALA* and F. DUKES-DOBOS
Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, 1014 Broadway, Cincinnati, Ohio 45202
*National Institute of Health, Bethesda, Maryland 20014

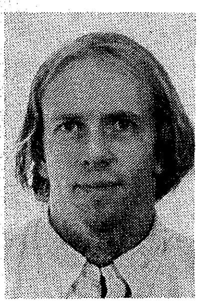
Introduction

Despite considerable research effort, the objective identification and quantitation of fatigue and work strain has not been fully realized, reflecting the complexity of the physiological and psychological events which take place during a stressful work effort. Tests designed to demonstrate fatigue by means of changes in biochemical,[1-4] psychological,[5,6] or physiological[7,8] parameters have had limited success and in many cases are known to be influenced by factors other than fatigue or are not practical for use in industrial settings. Substantial evidence has evolved, however, which indicates a relationship between changes which occur in the electromyogram (EMG) and the development of muscle fatigue.[9,10] Two forms of EMG analysis are most often employed. The integral or the root mean square voltage (rms) of the electrical activity may be computed to provide information concerning the power of the signal. In addition, the EMG signal may be analyzed into its component frequencies by use of electronic band filters or by "Fourier Analysis." These techniques are routinely used in a number of laboratories, and it has been repeatedly shown that the EMG signal rms in-

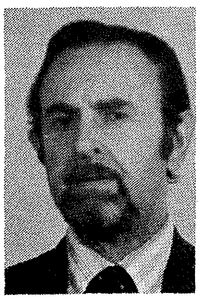
Gary Wright was born in Cincinnati, Ohio in 1945. He received a B.S. (Biology) degree from Eastern Kentucky University in 1966, an M.S. (Environmental Physiology) from New Mexico State University in 1968 and a Ph.D. (Mammalian Systems Physiology) from the Ohio State University in 1974. He has worked as an exercise-heat stress physiologist under C. F. Consalazio and is presently engaged in studies concerning heat stress, vibration stress and work-induced fatigue which are being conducted within the NIOSH Physiology and Ergonomics Branch.



Donald Wasserman was born in New Haven, Connecticut on April 1, 1939. He received a B.A. (Physics) degree in 1962 from the University of Connecticut and an M.S.E.E. (Electrical Engineering-Bioengineering) degree in 1971 from New York University. In 1971, he joined NIOSH as Chief, Bioengineering-Biomechanics Section, Physiology and Ergonomics Branch, where he is presently engaged in studies relating to the effects of occupational stressor on man.



Erik W. Pottala was born in Fitchburg, Massachusetts on November 15, 1939. He received a B.S. degree in Electrical Engineering from Worcester Polytechnic Institute in 1961, an M.E. degree from Yale University in 1963, and a Ph.D. degree in Electrical Engineering from the University of Maryland in 1970. He is currently involved with the development of hardware neural modeling and computer systems for the processing and preprocessing of biological data. Dr. Pottala is a member of Sigma Xi, Eta Kappa Nu, and PCA.



Dr. Francis N. Dukes-Dobos is Chief of the Physiology and Ergonomics Branch at the National Institute for Occupational Safety and Health in Cincinnati, Ohio, since October 1973. He obtained his M.D. degree from the Eotvos Lorand University, Budapest, Hungary in 1951. His research work has dealt mainly with the problems related to human tolerance to heat and physical work. He explored the metabolic, cardiorespiratory and automatic nervous responses of men exposed to stressful conditions.

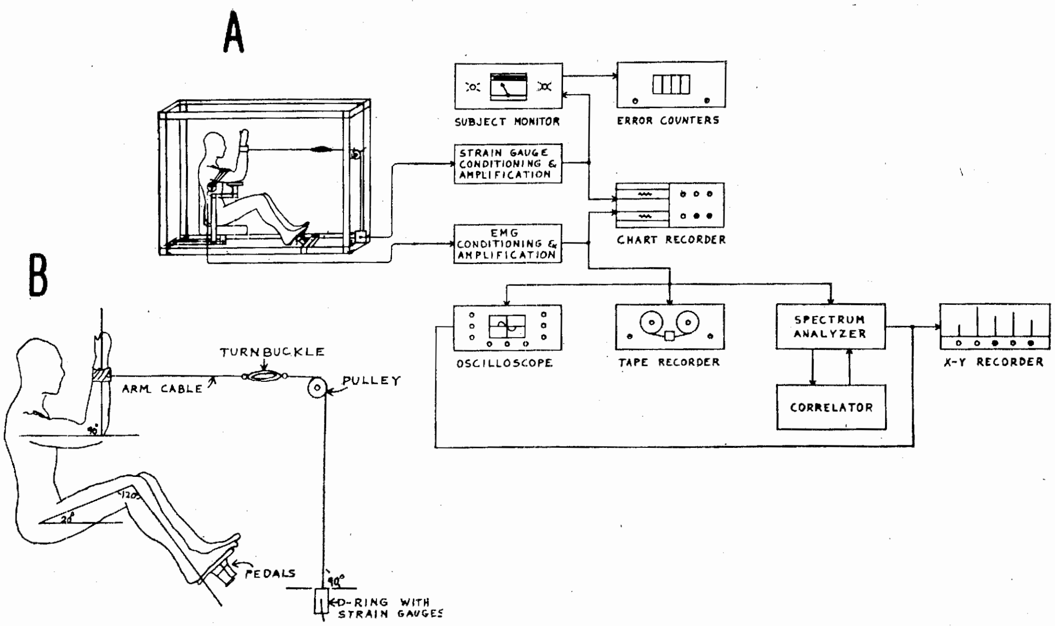


Figure 1—Strength and endurance instrumentation system. (A) General description of subject apparatus with associated monitoring and analysis equipment. (B) Subject contraction posture for elbow flexion in relationship to the load system.

creases[12,13] and the percent power shifts toward the lower end of the frequency spectrum[14,15] during a sustained muscle contraction.

The major portion of the work in this area has been concerned with alterations in the EMG as they relate to acute and localized muscle fatigue induced by isometric contraction. In contrast, little is known concerning the effects of general fatigue on the surface electromyogram. In the present study, isometric strength, endurance time, and EMG characteristics of the biceps brachii were examined following fatiguing treadmill exercise.

Materials and methods

Four male subjects ranging in age from 30 to 38 years were selected on the basis of no known previous cardiovascular or neuromuscular disease. The study consisted of two parts in which strength, isometric endurance, and electromyographic characteristics were examined before (9:00 a.m.) and after (2:00 p.m.) four hours of treadmill exercise (25 minutes exercise, 5-minute rest schedule) at either 50% or 60% of maximum aerobic capacity.[17] Each subject exercised four to six times at both work levels in addition to three control sessions during which lounging was substituted for the treadmill exercise. The exercise chamber was maintained at 22±1°C with relative humidity at approximately 50%. The strength-endurance apparatus has been previously described[16] and consisted of an isometric pull cable with strain gauges and appropriate amplifying and recording systems (Figure 1). Subjects were immobilized in the seated position by belt restraints and adjustable arm and foot rests. Electromyographic data were obtained from the biceps of the right arm with surface electrodes (Bectim-Dickenson Type "Disposo-El") placed in a linear fashion and parallel with the muscle with the ground interposed between the active and

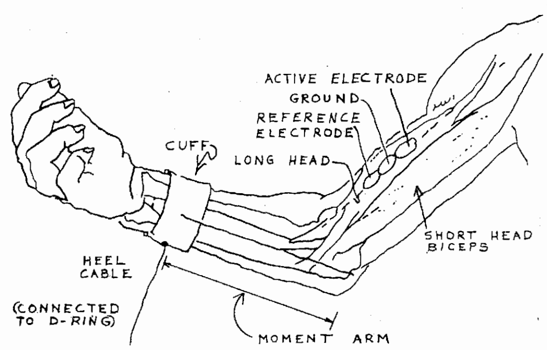


Figure 2—Electrode placement over the biceps brachii. Electrodes were attached to skin 15-30 minutes prior to morning tests and were left in position throughout exercise and afternoon testing to prevent variations in placement between tests.

reference electrodes (Figure 2). Data were recorded on magnetic tape for computer analysis and the total signal rms was determined for 1-500 Hz. Component frequencies were analyzed by Fourier analysis and the power ratio computed for 4-40 Hz. The EMG data were averaged over ten-second intervals, and the ten-second and fifty-second interval determinations were selected for statistical comparison. Group means were compared by Analysis of Variance and then by paired t-tests for significance at the 5% level if the Analysis of Variance indicated a significant difference. Within test values (10 vs. 50-second determinations) were analyzed by paired t-tests.

At the beginning of each strength-endurance test session, the subject underwent a series of three four-second maximum voluntary contractions (MVC). The endurance test was then performed at 60% of the average demonstrated maximum strength utilizing a display monitor showing relative loading. Subject instruction followed a procedure previously proposed,[18] and the subjects were simply told to maintain the contraction tension for as long as possible.

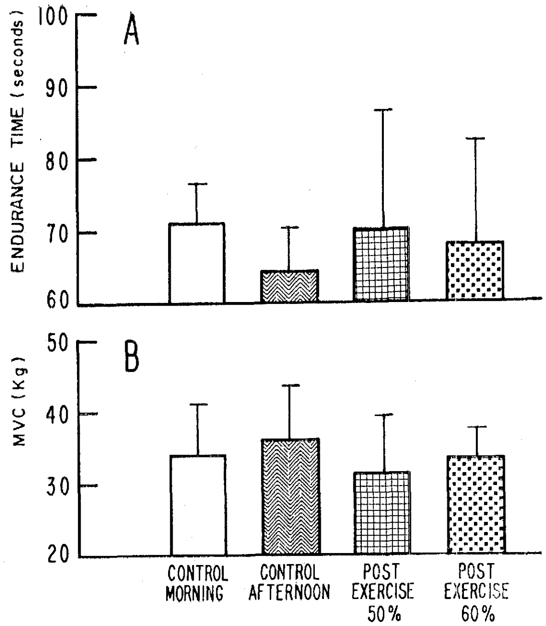


Figure 3–(A) Endurance time (seconds) for constant tension isometric contraction at 60% of demonstrated maximum strength. (B) Maximum voluntary contraction tension. The bar indicates the means values while the vertical line indicates one standard deviaiton of the mean.

Results

Although subjects consistently complained of subjective feelings of fatigue and exhaustion, the endurance time for maintaining isometric contraction of the biceps brachii at 60% of maximum tension was not significantly altered by treadmill exercise at 50% or 60% of maximum aerobic capacity (Figure 3). Afternoon control values for endurance time tended to decrease (10%) from those obtained in the morning tests, but the difference was not statistically significant. The average value obtained for isometric endurance time at 60% maximum strength throughout the test sessions was approximately 68 seconds. Similarly, the mean value obtained for maximum voluntary contraction tension were not significantly different among the different test sessions (Figure 3). Maximum voluntary tension for the biceps for the various sessions averaged 34 Kg.

The signal rms tended to increase during the course of the isometric contraction with mean 58%, 35%, 41%, and 97% increases noted between ten and fifty-second determinations for the morning, afternoon control, 50% and 60% exercise groups, respectively (Figure 4). These differences were not, however, statistically significant.

The percent power in the 4-40 Hz band of the EMG frequency spectrum increased significantly during isometric contraction. (Figure 5). Mean increases of 100%, 50%, 73%, and 83% were observed at fifty seconds in the morning, afternoon control, and post exercise 50% and 60% sessions, respectively. In addition, there was a significant increase in the percent power in the 4-40 Hz portion of the spectrum (ten-second interval determinations) between morning and afternoon tests. The magnitude of increase in power was similar among the afternoon control and post-exercise sessions indicating that the shift in power to the lower end of the frequency spectrum was related to the time of testing and was not significantly influenced by exercise.

Discussion

The surface electromyogram indicates the electrical activity of a muscle during voluntary or involuntary contraction. Its characteristics, in terms of total signal power and power distribution throughout the frequency spectrum have been utilized as a diagnostic tool for the detection of certain pathologies[19] as well as an index

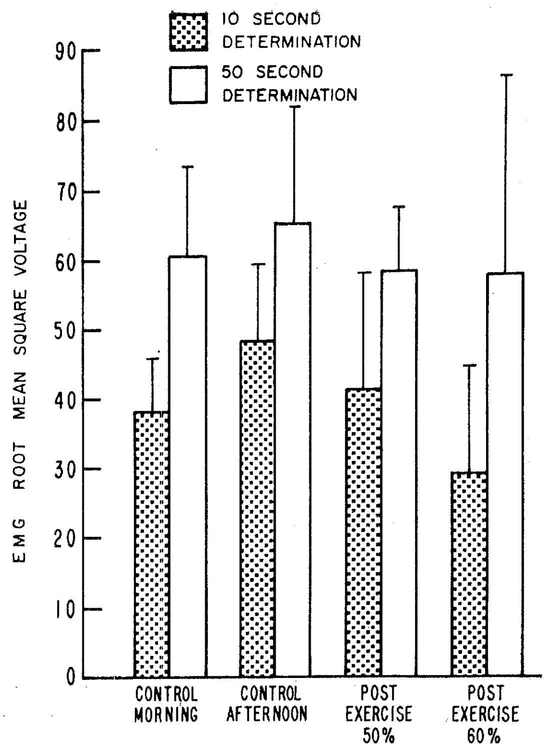


Figure 4—The EMG signal root mean square voltage during morning, afternoon control, and afternoon post-exercise testing. The bar indicates the mean while the vertical line represents one standard deviation of the mean.

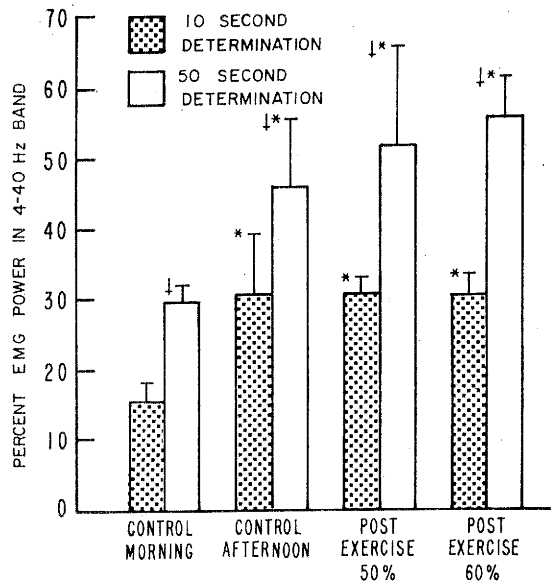


Figure 5—The percent EMG power in the 4-40 Hz portion of the spectra during morning, afternoon control, and afternoon post-exercise testing. The bar indicates the mean while the vertical line represents one standard deviation of the mean. A cross indicates a significant difference between 10 and 50-second determinations and an asterisk indicates a significant difference between comparable morning and afternoon values.

of the reversible changes which occur during fatiguing muscular activity.[9,10,15] The mechanism(s) which produce alterations of the EMG during fatiguing contractions are not clearly understood, but have been proposed to involve changes in the pattern (synchrony) of motor unit firing;[20] recruitment of additional, higher threshold and more slowly firing fibers[21,22] and alterations in electrophysiological characteristics of the conducting membranes due to blood flow occlusion and acid metabolite accumulation.[23,24] In view of the evidence supporting these hypotheses, it is probable that each plays a role in the EMG changes observed during the genesis of fatigue.

The findings that have been advanced relating alterations in the electromyogram with the state of fatigue stem mainly from studies of acute and localized fatigue, induced by sustained isometric contraction. On the other hand, the intact muscle is not an isolated entity, and it may be reasoned that the neural, humoral, or biochemical changes through which alterations in the EMG are mediated during acute fatigue may be at least partially operative during general fatigue. It has been shown that the signal power in both the active and passive muscles increases during isometric contraction.[25] However, the signal power observed in the active muscle during an initial control contraction was not significantly different from that obtained from the muscles of the opposite arm during a repeated contraction indicating the EMG was a relatively insensitive indicator of generalized muscular impairment. Futhermore, it has been demonstrated that there is no significant alteration in the EMG response of arm muscles during isometric contraction following vibration induced whole-body fatigue.[26] The investigation of the effects of leg exercise (treadmill) on isometric endurance time and EMG characteristic of the biceps brachii in women showed that immediately following a treadmill walk to exhaustion (average end heart rate = 198 bpm), the EMG spectra power distribution was unchanged during isometric contraction at approximately 40% MVC, but that the rate of power shift during the course of the contraction was increased corresponding to a 40% decrease in isometric endurance time.[27] These findings are in agreement with the data of the present study to the extent that the EMG signal rms or power distribution within the frequency spectrum was unaltered following four-hour periods of treadmill exercise at 50% or 60% of subject maximum aerobic capacity.

In view of the subjects' consistent subjective feeling of fatigue following the four-hour treadmill exercise periods, it may be concluded either that: (I) general fatigue induced by leg exercise does not appreciably elevate the state of fatigue of arm muscles, or (II) the EMG is a relatively insensitive indicator of general fatigue as it is reflected in arm muscle. The experiments showing a definite residual fatigue effect of leg exercise on arm muscle isometric endurance time in the absence of a significant effect on EMG properties,[27] suggests the latter hypothesis is probably correct. This further raises the question of how faithfully the EMG reflects fatigue per se. The shift in signal power distribution observed between morning and afternoon control sessions of this study (Figure 5) indicates that factors other than fatigue may markedly affect this parameter. The percent power occurring in the 4-40 Hz band in the afternoon session, ten-second determination was nearly twice that obtained at ten seconds and similar to the fifty-second value of the morning test. In comparison, subjects expressed little or no feeling of fatigue nor did the MVC and contraction endurance times suggest the existence of residual fatigue during afternoon control testing. It should be noted that the majority of the work that has been done relating fatigue with changes in the EMG has actually examined the alteration of the EMG as a function of the time course of contraction rather than the development of the fatigue mechanism(s). Studies correlating the EMG response to more definitive indicators of fatigue during static muscular activity reveal a relatively poor relationship. For instance, relating the percent EMG power in the 4-30 Hz and 60-100 Hz bands to the magnitude of hand tremor following weight holding showed correlation coefficients of 0.59 and 0.39, respectively.[15] It has been shown that the surface EMG trace may be experimentally altered by changes in blood flow[23] and local heating.[28] Other factors which may affect the surface EMG but not relate directly with fatigue include: water compartmentalization, electrolyte balance, endocrine function, nervous activity and subject psychological state and motivation. The present incomplete knowledge of the exact nature of the fatigue mechanism and its mode of action on the EMG indicates the need for caution in the evaluation of alterations in the EMG as a function of the state of fatigue of the individual.

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