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US ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY 40121

REPORT NO. 772

SUBJECTIVE AND ELECTROMYOGRAPHIC ASSESSMENT OF ISOMETRIC MUSCLE CONTRACTIONS

(Interim Report)

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UNITED STATES ARMY
MEDICAL RESEARCH AND DEVELOPMENT COMMAND

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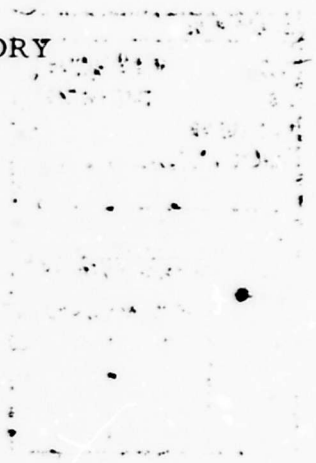

26 March 1968

Biomechanical Aspects of Performance and Performance Decrement
Work Unit No. 022
Military Psychophysiological Studies
Task No. 00
Military Psychophysiological Studies
DA Project No. 3A014501A74D

USAMRL Report No. 772
DA Project No. 3A014501A74D

ABSTRACT

SUBJECTIVE AND ELECTROMYOGRAPHIC ASSESSMENT OF ISOMETRIC MUSCLE CONTRACTIONS

OBJECTIVE

To determine the relationship of subjective, objective and physiological aspects of fatigue in an isometric task.

METHOD

Forty male subjects were assigned to pull either 25% or 50% of their maximum voluntary contraction on an isometric dynamometer handle. While maintaining the load as long as possible they were asked to concentrate on the pain experienced in the active muscles and to rate it on a five-point scale. During the task, the tension in the active muscle was continuously monitored by an EMG.

SUMMARY

The mean EMG amplitudes for the five pain intensities indicated that a submaximal tension was required to sustain the contraction. The EMG amplitude showed a significant increase over the initial level only near the termination of the task.

CONCLUSIONS

The results indicated that, by the EMG monitoring of the tension of an active muscle during an isometric endurance task, a time could be distinguished where cortical recruitment was required to maintain the contraction. Localized control of motor unit activity was sufficient to maintain the required tension level during the initial portion of the endurance task. With localized muscle impairment, subjective elements determined the final stage of the endurance.

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INTRODUCTION

The concept of fatigue has been utilized in a variety of contexts relating to human behavior. A series of operational definitions have resulted where fatigue has been typed as intellectual, physical, or physiological in origin. In the present experiment, fatigue is measured by the subject's assessment of his condition in reference to the task requirements (1). To make an assessment, an individual should evaluate the sensory information derived from the induced physiological imbalance, the increasing effort required to maintain a constant output, and such motivational factors as the increase in boredom and the need to escape from an increasingly aversive situation.

Few efforts have been made to incorporate all the major sources of information contributing to the individual's analysis of his fatigue state. Caldwell and Smith (2, 3) have demonstrated a relationship between a subjective assessment of several of the stimuli associated with fatigue (pain, effort, and reserve) and the objective measure of endurance of an isometric muscle contraction. Hosman (6) found similar results in a cross-modality matching procedure where subjects matched auditory intensities to subjective intensities of fatigue in a weight-lifting task. These results indicated that individuals are capable of reliably estimating their endurance in a physical task. Eason (5) further indicated a relationship between the objective measure of maximal endurance and electromyographic activity. Although the relationship was significant, he found that voluntary effort, cortical in origin, was an intermediary variable of critical importance. In these studies, a definite relationship has been demonstrated between the subjective and objective aspects of a fatigue state.

The present study attempts to relate the subjective, objective, and physiological aspects of fatigue by examining the relationship of an individual's subjective estimation of fatigue to the physiological levels of muscle tension and to the objective measure of endurance of an isometric muscular contraction.

METHODS

The subjects consisted of 40 male volunteers of college age (17 to 23 years with a mean of 19 years). No effort was made to control for any

physical characteristics of the subjects except for the elimination of any with physical disabilities.

The apparatus consisted of an adjustable isometric hand dynamometer mounted from the right side of the subject's chair, and a stabilizing handle mounted on the left. Four strain gauges wired as a Wheatstone bridge were mounted on the dynamometer handle. The output from the gauges was amplified by a low-level d-c preamplifier and recorded by an ink-writing recorder. In addition, a voltmeter calibrated in pounds and wired in parallel with the recorder provided the subject a direct indication of his output.

Bipolar recordings of electromyographic activity (EMG) were obtained by Beckman silver-silver chloride surface electrodes placed 2 in. apart from the center of the long head of the biceps muscle of the right arm. This EMG activity was fed into a Grass Model 5P3 integrator with a 0.2 sec. time delay. An indifferent electrode was placed on the left ear lobe.

PROCEDURE

After informing the subject of the general nature of the experiment, he was positioned in the chair. The dynamometer was adjusted so that the right arm was parallel to his side and his forearm was parallel to the floor. Stability was maintained by the adjustable handle for the left hand, and by footplates mounted on the chair frame which were adjustable to produce a leg-to-thigh angle of 150°.

The areas of the skin for the electrodes were scrubbed with a 70% alcohol solution and the electrodes were secured with adhesive collars. Proper electrode contact was insured by the utilization of electrode jelly. A check insured the resistance across the electrode to be no greater than 10,000 ohms.

The subject was instructed to pull maximally three times; his strongest pull was taken as his maximum strength. There was a 3-min. rest period between each of the maximum pulls. The subject was assigned to either a 25% or 50% of maximum contraction conditions. The order of assignment was determined by the ABBA method of counterbalancing. There was a 5-min. rest period between the pre-trials and the first scaling trial.

Each subject was informed what percentage of the maximum he was to maintain and what that value was in pounds on the voltmeter. He was

also informed that while monitoring the load, he was to concentrate on the pain experienced in the muscles actively engaged in the task and to rate it on a five-point scale. The first point on the scale was defined as "just noticeable pain"; the fifth point was defined as "intolerable pain—the point at which he could no longer maintain the load". It was his task to report the different pain levels when he felt they occurred. The experimenter noted the times of occurrences of the subjective estimates by an event marker on the recorder.

Each subject received two trials separated by a 15-min. rest period. Continuous EMG recordings were made during the three pre-trials and the two experimental trials.

RESULTS

The mean contraction times for the five judgments of pain intensities are presented in Figure 1. The results of an analysis of variance indicated that the mean endurance levels were statistically different between the 25% and 50% load, between the two trials, and between the five subjective estimates of pain ($p < .01$). Significant interaction effects were also obtained for the loads by estimates, loads by trials, estimates by trials, and the loads by estimates by trials interaction ($p < .01$).

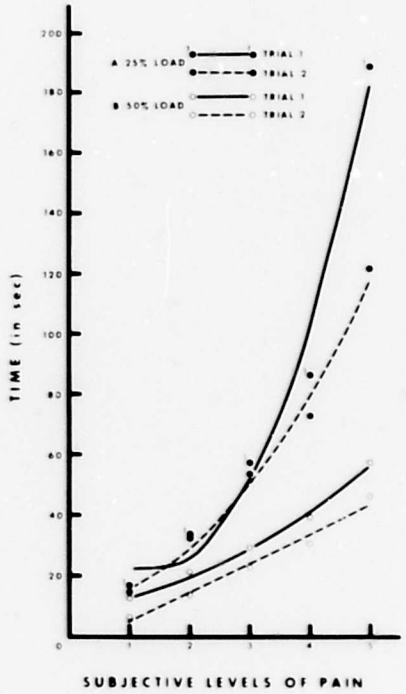

Fig. 1. Mean contraction times for the five judgments of pain intensities.

The functions for each of the four sets of mean endurance times in Figure 1 were determined by the use of orthogonal components in the test for trends (10). For the 25% load, the pain-endurance curves presented are the derived quadratic function. Over 97% of the variance was attributable to the linear and quadratic components ($p < .01$). When the 50% load was considered, the mean endurance levels of trial one were determined to be a quadratic function. Ninety-nine point four percent of the variance was accounted by the significant linear and quadratic components ($p < .01$). The only significant component in trial two was linear ($p < .01$), accounting for 97.7% of the variance.

The large quadratic components in trial one of both loads indicated a tendency for the subjects to underestimate their maximal endurance pain. Though an initial experience with the procedure, this underestimation was reduced as indicated by the tendency toward a linear function in trial two.

The continuous record of electromyographic activity of the biceps muscle was manually digitized by determining the median amplitude of the integrated activity for continuous 10-sec. samples throughout the trials. The mean EMG amplitudes in microvolts determined for the five estimates of pain intensities are presented in Figure 2 (next page). An analysis of variance revealed a significant difference in EMG amplitude between the two loads of 25% and 50%, the two trials, and between the five levels of pain. The interaction of loads by estimates was also statistically significant ($p < .01$).

The initial EMG level at 50% was approximately twice the amplitude of the initial EMG level at 25%, thus indicating that EMG amplitude is positively related to muscle tension as previously suggested (8).

The mean EMG intensities for the five estimates under each condition were subjected to a Newman-Keuls test in order to determine where the increase in EMG amplitude occurred. When subjects sustained the 25% load, the only significant increase in EMG amplitude occurred in the final interval of trial one where the mean activity at pain level five was greater than that which occurred at levels one, two, and three. In both trials of the 50% contraction there was a statistically significant increase in EMG activity at the final levels of pain intensity. The EMG amplitude at level four was greater than at one and two; and at level five, it was greater than one, two, and three.

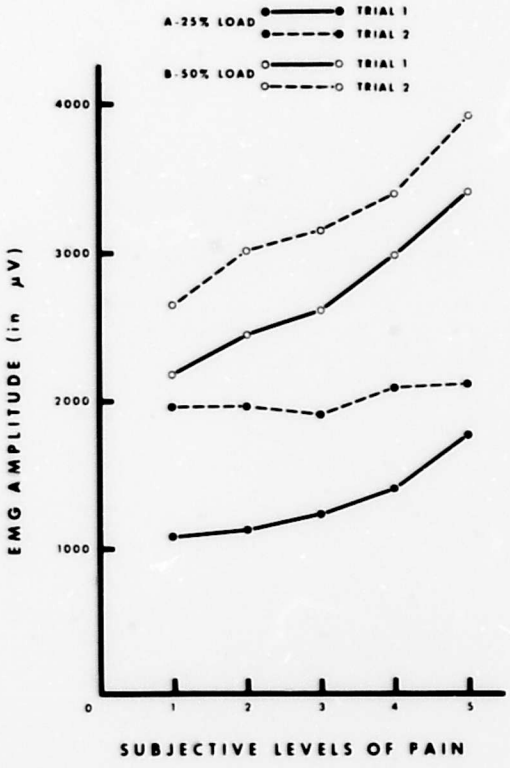

Fig. 2. Mean EMG amplitudes for the five estimates of pain intensities.

DISCUSSION

Although the subjects were instructed to concentrate only on the localized pain produced by the active muscles during the isometric contraction, there was no guarantee that this was the only stimulus being utilized. Caldwell and Smith (3) evidenced a considerable relationship between pain, effort, and reserve scaling during a similar procedure. These factors could readily have been available for utilization by the subject. In addition, the aversive stimulus of pain may not necessarily have been localized in the biceps muscle. Considerable pressure of the hand was required to maintain a grip on the dynamometer handle. Yet the results indicated that subjects, when concentrating on an available stimulus during an endurance task, are able not only to estimate their maximal endurance but also to estimate it at the early stages of the task. Although a significant underestimation was evidenced at the 25% load, it is predicted that several additional trials would tend to reduce this.

The commonly accepted source of the early onset of fatigue during physical endurance tasks has been the localized ischemia produced by the muscle contraction. This ischemia could also be the source of the localized pain which the subjects were instructed to concentrate upon and rate. Caldwell and Smith (2) found that the rate of increment of reported pain increased as a result of impaired limb circulation. Yet it is difficult to comprehend this concludion when previous experiments have shown that a submaximal muscle contraction during an isometric task does not produce sufficient mechanical compression to occlude the localized blood supply (7, 9). In addition, Humphreys and Lind (7) demonstrated that the blood flow through the active muscles actually increased at hand-grip tensions up to 70% of maximum contraction strength. This is not to say that ischemia was not the source of pain. The subjects verbally reported that the greatest difficulty in sustaining the contraction was in maintaining a grip on the dynamometer handle. At the termination of a trial, they described their hand as "cold and numb" which would be indicative of sufficient compression to produce localized occlusion of the blood supply. Thus the pain being rated in a trial could very well have been ischemic pain in the hand.

The results of the analyses on the EMG indicated that a submaximal tension in the active muscle was required to maintain the contraction. This was most evident at trial two of the 25% load where the mean amplitude remained at a constant level throughout the duration of the contraction. The other trials demonstrated an amplitude increase only near the termination of the task. These analyses suggest that a measure of muscle tension by the EMG can differentiate between the psychological and physiological aspects of fatigue in an isometric task.

The endurance time during which there was no significant increase in EMG amplitude of the active muscle was interpreted to be the time during which localized recruitment of the motor units was sufficient to maintain the necessary tension level. The point in time when the EMG amplitude significantly increased is suggested as the point of localized fatigue of the active muscle where additional recruitment, possibly cortical in nature, was necessary to sustain the required tension level. Therefore, the final portion of the endurance time which is under cortical control was then interpreted to be the interval during which the subjective elements of the fatigue situation mentioned above would determine its length. This is also the time the experimenter consistently noted an occurrence of tremors in the arm which irradiated throughout the subject's body.

The individuals who participated in the present experiment were not provided an incentive for their performance. This became an important factor in trial two of the 25% load. The results showed no localized impairment in the active muscle, even at the termination of the trial. With an increased incentive, it is predicted that maximal endurance will increase with an accompanying increase in EMG amplitude.

An amplitude increase in EMG has been suggested by Close (4) to result from a change in the firing of individual motor units from a desynchronized pattern at low tension levels to an increase in synchronization as the tension level increases. Eason (5) suggested that during an isometric endurance task, localized impairment of motor units require the introduction of additional recruitment which is cortical in origin. This cortical recruitment coupled with local fatigue of the motor units could be the source of the increased synchronization which occurred near the termination of the endurance task.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
US Army Medical Research Laboratory
Fort Knox, Kentucky 40121

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
SUBJECTIVE AND ELECTROMYOGRAPHIC ASSESSMENT OF ISOMETRIC MUSCLE CONTRACTIONS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Interim Report

5. AUTHOR(S) *(First name, middle initial, last name)*
Andree J. Lloyd, CPT, MSC (Ph.D.), Joseph H. Voor, Ph.D., and Thomas Thieman, A. B.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
26 March 1968	8	10

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 3A014501A74D	772
c. Task No. 00	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. Work Unit No. 022	

10. DISTRIBUTION STATEMENT
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	US Army Medical Research and Development Command, Washington, D. C. 20315

13. ABSTRACT

Forty male subjects were asked to pulleither 25% or 50% of their maximal voluntary contraction on an isometric dynamometer handle. During the pull, they were asked to rate the pain experienced in the muscles on a five-point scale. During the task, the active muscle was continuously monitored by an EMG. (U)

The results indicated that individuals are able to predict their maximal endurance when concentrating on a dominant stimulus in a physical task. The EMG analyses indicated that a differentiation can be made between physiological and psychological aspects of fatigue. The point in time when the EMG significantly increased in amplitude is interpreted to be the time when, due to motor unit impairment, the active muscle is fatigued. Additional contraction time was proposed to result from cortical recruitment, the length of which was determined by motivational elements. (U)

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fatigue						
Endurance						
Electromyography						
Pain Assessment						
Work						
Muscle Tension						
Isometrics						