US ARMY MEDICAL RESEARCH LABORATORY

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REPORT NO. 981

THE EFFECT OF TRAINING ON PERFORMANCE EFFICIENCY DURING A COMPETITIVE ISOMETRIC EXERCISE

(Interim Report)

by

CPT Andree J. Lloyd, MSC

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UNITED STATES ARMY
MEDICAL RESEARCH AND DEVELOPMENT COMMAND

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CPT Andree J. Lloyd, MSC

US ARMY MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky 40121

and

J. H. Voor, Ph.D.

Department of Psychology
BELLARMINE COLLEGE
Louisville, Kentucky 40205

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13. ABSTRACT

Fifteen male college students participated in a competitive isometric exercise involving elbow flexion. The men were grouped into five teams each consisting of three men. A prize of $25 was offered to the team which maintained the greatest force for the longest time. Prior to the competitive session each subject practiced individually on the apparatus for eight sessions. The men were randomly assigned to the teams on the day of the competition. During each session, continuous EMG recordings were made on the biceps muscle of the right arm. Training significantly improved both strength and endurance while reducing the average EMG amplitude. The highest level of performance for the group was obtained in the final training session. When team competition was introduced, there was a decrease in endurance and an increase in EMG amplitude. It was concluded that training improved muscular strength and endurance by increasing the efficiency of muscle utilization. Competition, even with a partially trained skill, was considered a stressful situation that produced an overexpenditure of muscle activity and a resulting decrease in performance.

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ABSTRACT

THE EFFECT OF TRAINING ON PERFORMANCE EFFICIENCY DURING A COMPETITIVE ISOMETRIC EXERCISE

OBJECTIVE

To study the influence of training on muscular efficiency during an isometric exercise involving team competition.

METHODS

Fifteen male college students participated in a competitive isometric exercise involving elbow flexion. The men were grouped into five teams each consisting of three men. A prize of $25 was offered to the team which maintained the greatest force for the longest time. Prior to the competitive session each subject practiced individually on the apparatus for eight sessions. The men were randomly assigned to the teams on the day of the competition. During each session, continuous EMG recordings were made on the biceps muscle of the right arm.

SUMMARY

Training significantly improved both strength and endurance while reducing the average EMG amplitude. The highest level of performance for the group was obtained in the final training session. When team competition was introduced, there was a decrease in endurance and an increase in EMG amplitude.

CONCLUSION

Training increased muscular strength and endurance by improving the efficiency of muscle utilization. Competition, even with a partially trained skill, was considered a stressful situation that produced an overexpenditure of muscle activity and a resulting decrease in performance.

THE EFFECT OF TRAINING ON PERFORMANCE EFFICIENCY DURING A COMPETITIVE ISOMETRIC EXERCISE*

INTRODUCTION

Competition has been utilized as a source of motivation in situations where maximum performance is encouraged. Its facilitating influence has been well documented in the performance records of a myriad of athletic contests. Further support of this effect can be found in controlled experiments (6,9). Wilmore (9) observed that competition produced a significant increase in endurance on a bicycle ergometer but with no significant increase in the measured physiological indices of heart rate $\dot{V}$, or $\dot{V}O_2$. Such results have led to an implicit assumption that competition is a reliable means of improving performance. However, when Voor, et al (8) introduced team competition as a motivator in an experiment involving the measurement of maximum isometric endurance, contraction time was not increased. Electromyographic (EMG) measures of the activity of the dominant muscle demonstrated that a significantly greater level of muscle activity was required during competition for the same relative force and endurance.

Evidence has accumulated to demonstrate that an EMG is reflective of more than the minimal level of tension required to perform a task (1, 3,5,8). Eason (1) observed a nonlinear increase in EMG amplitude during the course of maintaining a constant force and proposed it to result from an increase in the voluntary control required to maintain the contraction. Although such a progression typically occurs during fatigue development, any situation which would intensify or induce an earlier onset of voluntary control--as demonstrated by increased EMG amplitudes--might be considered a source of stress. This type of increased activity could reflect an excessive utilization of muscle which should decrease endurance. The results obtained by Voor, et al (8) suggested that competition is a means of increasing arousal; whether it improves or degrades performance depends upon the level of arousal produced. This interpretation is consistent with the inverted U hypothesis of Malmo (4). With the foregoing in mind, it is proposed that the influence of competition is dependent upon the task skill of the individual since skill acquisition is associated with reduced arousal. Competing in a relatively unlearned task appeared to degrade performance. Conversely, a competitive situation utilizing a trained (learned) response should improve performance. The purpose of the present investigation was to assess the effect of competition on the performance efficiency of a trained isometric exercise.

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METHODS

Fifteen male college students volunteered to participate in the present study. No effort was made to control any physical characteristics. When each subject arrived for the first session, a verbal contract was made to insure their continued participation over the nine required sessions. They were informed that the experiment was concerned with changes in muscle activity during an isometric exercise. They were told that the purpose of the first eight sessions was to increase their strength and endurance. Following the last practice sessions, they were informed that they would be randomly grouped into five teams of three men each and, in the final session, the teams would compete in terms of a combined maximum strength and endurance score for a $25 cash prize. The contract further stipulated that each participant would receive $1.25 per session payable only upon completion of the entire series of trials.

The apparatus utilized in the isometric exercise involving elbow flexion has been described previously (8). It consisted of a chair, two adjustable handles, and a footplate all mounted on a platform. The isometric handle to the right of the chair was mounted to an adjustable base with a ball-and-socket joint. Beneath the joint strain gauges were mounted in a Wheatstone bridge on a spring steel ring. A current imbalance in the bridge produced by a force on the handle was amplified and recorded on an ink-writing recorder. Direct information of the applied force was provided to the subject by a voltmeter wired in parallel with the strain gauge amplifier and calibrated in pounds of force.

Bipolar recordings of EMG were obtained by silver-silver chloride surface electrodes positioned 5 cm apart and centered over the long head of the biceps muscle of the right arm. An indifferent electrode was positioned on the ear lobe. Direct EMG signals were amplified through a Grass 5P3 amplifier and simultaneously recorded on an ink-writing polygraph and on an FM analog tape recorder with a frequency range of D.C. to 1000 Hz.

In each session the seated subject was positioned so that when gripping the isometric handle palmar side up, there was a 90° elbow angle when the upper arm was parallel with his side. The left handle was adjusted to maintain the left arm parallel to his side and perpendicular to the platform. A leg-to-thigh angle of 150° was provided by adjustable footplates.

The EMG electrodes filled with commercial electrode paste were mounted on the arm after thoroughly cleansing the skin with a 70% alcohol solution. Scrubbing was continued until measured resistance across the electrodes was reduced to less than 10,000 ohm.

At the beginning of each session the subject pulled maximally on the handle three times. Each maximum pull lasted approximately 3 sec and there was a 3 min rest period separating them. The strongest pull was utilized as his maximum voluntary strength.

The subject was informed that he was to maintain a force equal to 50% of his maximum pull; this value was identified for him on the voltmeter display. He was also informed that while monitoring his output, he was to concentrate on the pain associated with the muscular activity and to rate it on a five point scale. The first point was defined as "just noticeable pain;" the fifth point was defined as "intolerable pain--the point at which he could no longer maintain the force." His task was to report the different pain levels when he felt they occurred. The experimenter noted the times of occurrences of the subjective estimates by activating an event marker on the recorder.

A session consisted of the three strength trials and two endurance trials separated by a 10 min rest period. Continuous EMG recordings were taken during both endurance trials. At the end of each session, the subject was informed of his endurance time for each of the two trials. All training sessions were separated by a minimum of 24 hr and a 48 hr break intervened between the last training session and the competition. The subjects were randomly assigned to the five teams on the day of the competition. When competing for the team prize, the procedure was identical to the training sessions except that as one team member was being run, the other members of the team were in the testing room encouraging him to do his best.

RESULTS

The mean contraction times for the five estimates of pain intensities are presented in Figure 1. The characteristics of these cumulative endurance functions are similar to those found in previous studies (3,7,8). There appeared to be an initial underestimation of pain tolerance in the first training sessions supported by the nonlinearity of the functions principally between estimates 4 and 5. With practice, the men not only increased their endurance time, but also were more consistently linear in their judgments of a pain stimulus associated with the exercise. These conclusions were supported further by the results of the analysis of variance computed on the noncumulative endurance times. The results indicated that there was a significant difference in the mean endurance times among the nine sessions and five estimates ($p < .01$). However, the mean endurance times between the two trials were not significantly different ($p > .05$). All interactions among trials, sessions, and estimates were significant ($p < .05$).

The continuous record of biceps EMG activity that was stored in analog form on the FM tape was digitized by the following procedure. The signals were electronically averaged by passing them through a voltage-to-frequency-converter and stored in a counter. Internal controls on the counter provided continuous 1 sec integration periods which were printed on a 5 digit printer. Conversion of the printed data by

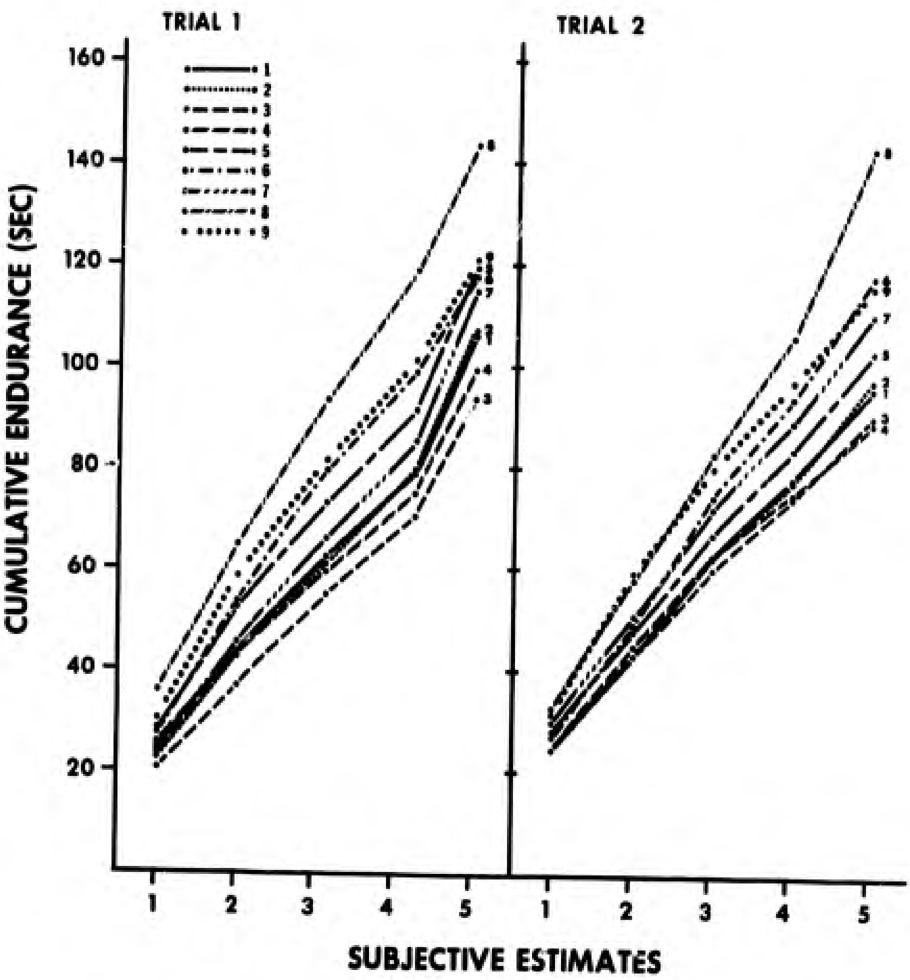

Fig. 1. Mean cumulative endurance times for the five subjective judgments of pain intensities during the nine sessions consisting of two trials each.

constant amplification values provided an average EMG amplitude per second in mV. The mean amplitudes were grouped into intervals determined by the subjective pain estimates. Therefore, although absolute endurance times varied for each trial and subject, this procedure provided five values of EMG amplitude which occurred at subjectively equivalent times during the course of the isometric contraction. The mean EMG amplitudes for the five judgments of increasing pain intensities are presented in Figure 2. An analysis of variance computed on these data revealed that the mean EMG amplitudes between the two trials, among the nine sessions, and among the five estimates were significantly different (all $\underline{p} < .01$). The differences in the slopes of the functions of Figure 2 were significant as indicated by the Sessions X Estimates interaction ($\underline{p} < .01$). None of the remaining interactions were statistically significant (all $\underline{p} > .10$).

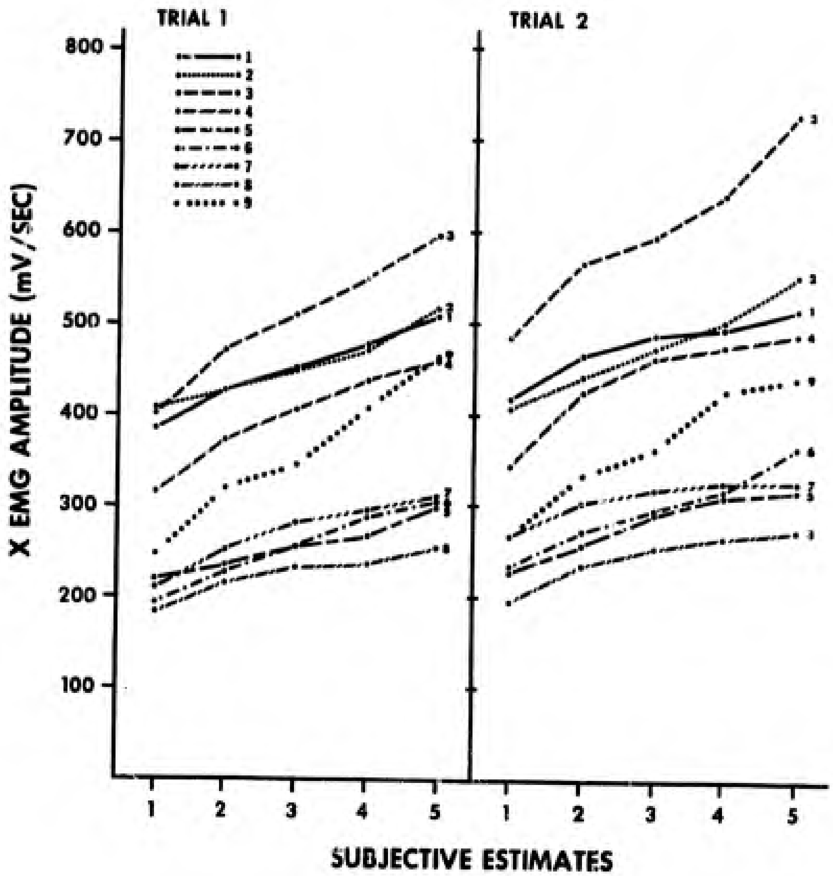

Fig. 2. Mean EMG amplitudes for the five estimates of pain intensities during the nine sessions consisting of two trials each.

The strength of the men in the present experiment increased during the training sessions. The lowest mean 50% of maximum force that was pulled on the isometric handle was 9.39 kg obtained in session 1. By session 8 the mean force increased to 12.06 kg. A t test revealed that the difference between these means was statistically significant (t = 6.41, df = 14, $p < .01$). However, there was no significant increase in strength between the last training session and the competition session where the mean 50% of maximum force was 12.47 kg (t = 1.81, df = 14, $p > .10$).

The relationship among the three measures of 50% maximum voluntary strength, maximum voluntary endurance, and the average EMG amplitude for each trial throughout the nine sessions is presented in Figure 3. These results demonstrated the significant increase in strength and endurance during training with a concomitant decrease in EMG activity. When placed in a competitive situation, endurance decreased and EMG activity rose.

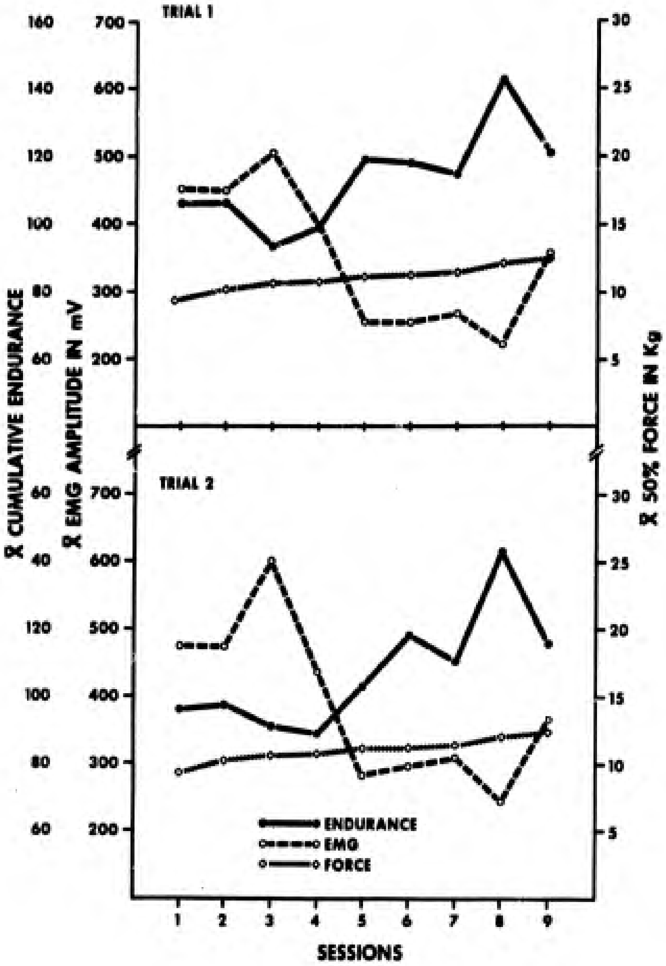

Fig. 3. The relationship between mean maximum endurances, 50% maximum strengths, and EMG amplitudes for the two trials in each of the nine sessions.

DISCUSSION

Present experimental results indicate that training results in improvement in both strength and endurance with a decreased activity level in the dominant muscles. The isometric apparatus and the utilization of the relative loading procedure provided an opportunity to observe isometric performance during a sustained contraction with a minimum of intersubject variability (2). It was interesting to observe the strategies apparently employed by the men. The results illustrated in Figure 3 indicated that essentially two levels of performance were utilized during training. During sessions 1 to 4 the men appeared to be concerned with strength improvement with little concern for any increase in endurance. Beginning in session 5, there was an abrupt increase in endurance with a slight steady increase in strength.

The anticipation of the competition session appeared to have an influence throughout the entire experiment. Even in the first trial the mean maximum endurance of 106.2 sec was considerably greater than the greatest average group endurance of approximately 73 sec reported by Voor, et al (8) utilizing the same apparatus with a 50% maximum isometric force.

The results shown in Figure 3 further indicated that accompanying any increase in endurance there was a dramatic decrease in the EMG amplitude. For example, the average endurance increase from session 4 to 5 was 17.2 sec. At the same time, average EMG amplitude decreased by approximately 150 mV. A more marked relationship was observed in session 8 where the greatest maximum voluntary endurance occurred with the lowest EMG amplitude.

It appeared that the participants in the experiment were motivated throughout the experiment both by an investment of time and the opportunity to win. Since only 10 min was provided between the trials of each session, previous experimental results would suggest a performance reduction in trial 2 in terms of decreased endurance and increased $\bar{X}$ EMG amplitude when compared to trial 1 (7,8). However, in several sessions throughout the experiment there was little difference in endurance time. Amplitude EMG increases also were less than anticipated in several sessions.

It has been suggested above that EMG measures of levels of muscle activity reflect more than the minimal tensions required to sustain an isometric load. This was supported by the present experimental results. Increasing motivation during training through the anticipation of the competitive session resulted in increased performance measured by endurance time and maximum voluntary strength with decreased EMG activity, a result not obtained when competition did not follow a series of training sessions (7). Performance increased when muscle efficiency was improved. Training provided the opportunity to develop the combination of minimal muscle activity with maximum performance. Perhaps the increased endurance with lack of change in physiological measures during the competitive ergometer exercise of Wilmore (9) could be explained by a similar process. Optimum conditions were provided to obtain maximum performance during both the training and competition sessions. Zajonc (10) in a review of motor performance studies, determined that the presence of an audience improved the performance of a previously learned response and degraded performance in an unlearned task. The training sessions in the present experiment were provided on an individualized basis while the limited audience of the other team members were present only during the actual competition session in order to obtain maximum performance in all sessions. That competition remained as an effective source of performance degradation in the present experiment was indicated by the decreased endurance and by the significant increase in EMG amplitude in session 9. It was possible that the present procedure did not provide sufficient training to allow for stable maximum performance prior to competition. However, maximum endurance and the force sustained on the handle during the competitive session were greater than the results of the early training sessions.

In the present experiment where limited subject training was provided on an isometric exercise, performance enhancement was achieved during the anticipation of competition, rather than the actual contest. It appears that in order to obtain the increase in performance observed during athletic contests, at least two conditions must be met which were not available in this procedure: (1) an asymptotic level of performance should be reached during training and (2) the stress of competition must be subjected to adaptation. In situations where these conditions are not met, the competitor tries too hard and his performance is reduced. Since competition is provided universally as a source of motivation for performance enhancement, one must be aware of both types of influence and the resulting effects of each.

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