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MANUAL DEXTERITY, GRIP STRENGTH AND LEVEL OF ENDURANCE

RESEARCH REPORT

Presented in Partial Fulfillment of the Requirements
For the Degree Master of Engineering, Industrial
Engineering Department of Texas A&M University

BY

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ABSTRACT

This research is designed to answer the following questions: (1) does prior loading in terms of grip-holding cause a decrement in manual dexterity; (2) if a decrement does exist, how long does it last; and (3) can decrement be predicted from the amount of endurance to which subjects are loaded?

In answering these questions, ten male subjects are tested for manual dexterity using a Purdue Pegboard. These tests are presented before and after various conditions of grip loading, and differences in scores on these two tests are analyzed. Conditions of loading are determined using a previously developed formula for endurance. Variables in this formula are related to time and percentage of maximum strength.

Conclusions drawn from the analyses are as follows: (1) muscular loading in the form of grip-holding causes a decrement in manual dexterity; (2) this decrement lasts for a period of ten seconds or less; and (3) there is a relationship between the amount of endurance required by loading and the decrement caused by that loading.

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CHAPTER I

INTRODUCTION

Human body strength and associated levels of endurance are important topics in biomechanical research (Damon, Stoudt and McFarland, 1966). Other topics included in biomechanics are range and speed of body movements, and the composition and response of the human body to physical forces of the environment. It follows, therefore, that biomechanical data frequently become design criteria for tools, layout and arrangement of a work station, and personnel protection.

Another general area for research and application is that of relating production efficiency of a worker to the biomechanical requirements of the task in which he is engaged. Of course, it is easy to see that if task design features do not meet established biomechanical criteria, efficiency will be impaired. But suppose, criteria have been met; what now can be said regarding efficiency? Data for resolving this question are not prevalent in the literature, and what does exist is either related to energy expenditure rather than production efficiency or it is task specific or both. Current reviews of this material are provided by Streimer (1968) and Davis, Faulkner and Miller (1969).

The need of a systematic program of research to relate biomechanical requirements of a worker's task to his production efficiency seems apparent. The resulting data would serve as important inputs to production scheduling, work-rest cycles, production rates and associated time standards. To initiate such a program, a researcher has two alternatives. He can either make use of specific tasks presently existing in the industrial environment or he can utilize basic human abilities devices. Selecting either one of these approaches depends upon the bias of the researcher. However, the present author feels that since these latter devices can be used to measure the basic abilities which underlie specific task skills, they are perhaps the logical place to start. In the present investigation, the basic human ability chosen for study is manual dexterity. The biomechanical factors of interest are grip strength and grip-holding endurance.

Problem

The primary research question which this investigation is designed to resolve is: 1) does prior muscular loading in terms of grip-holding endurance affect performance in a manual dexterity task? To resolve this question, manual dexterity performances of human subjects, as measured by the Purdue Pegboard, are compared before and after loading on a grip device. If prior grip loading causes a decrement in manual dexterity, two additional research questions are: 2) how long does the decrement last; and 3) can performance decrement be predicted from known relationships between levels of endurance, maximum force application and recovery time? The former is determined by time-sampling dexterity performance and comparing these performance scores with predetermined base line levels. The latter question is answered by comparing the decrement caused by differential loadings derived from Rohmert's equation (Caldwell, 1970) relating endurance and maximum holding time.

Research Hypotheses

With regard to the previous research questions, the following hypotheses are suggested: 1) Prior loading in the form of grip-holding causes a decrement in subsequent manual dexterity; 2) The time span for this decrement is short term, less than one minute; and 3) Decrement can be predicted by the amount of prior endurance levels to which the participants are subjected. To test these hypotheses a 95% confidence level is adopted.

Summary

This paragraph provides a brief summary of the balance of the report. Chapter II contains a review of the literature pertaining to the parameters which are important in this research. These parameters are manual dexterity, grip strength and endurance, and recovery time. The method and apparatus used are described in Chapter III. Chapter IV gives a summary and discussion of the results. Conclusions and recommendations are contained in Chapter V.

CHAPTER II

LITERATURE REVIEW

Biomechanical research has dealt primarily with those factors affecting such variables as range, strength, and speed of human movements and the response and composition of the human body. Three general classes of factors have been identified - biological, psychological and environmental. A review of the research in these three areas, specifically related to equipment design is provided by Damon, Stoudt and McFarland (1966) and will not be repeated here. Of particular interest to the present study is a review of research associated with manual dexterity, grip strength and endurance, and recovery from muscle loading. An abundance of material is available on these factors; however, in the review which follows, attention has been given only to those studies which provide guidelines for conducting the present investigation.

Manual Dexterity

Manual dexterity is the ability to make rapid, skillful, controlled manipulation movements of objects where the fingers, arms and hands are primarily involved. Fleishman and Hempel (1954) have developed a much finer analysis of dexterity, providing support for five primary dexterity factors which include:

1) Finger dexterity or fine dexterity: the ability to coordinate finger movements in performing fine manipulations;

2) Manual dexterity: the ability to make skillful arm and hand movements;
3) Wrist finger speed: rapid wrist flexing and finger movements;
4) Aiming: the ability to perform quickly and precisely a series of movements requiring eye-hand coordination; and
5) Positioning: ability to place objects in snugly fitting holes.

The practical utility of such a fine analytical breakdown remains to be demonstrated. For this reason, the present author has chosen to combine factors (1) and (2) into a single ability called manual dexterity. Even Fleishman and Hempel have found that these two factors are highly correlated on simple tasks.

One of the more frequently used devices to measure manual dexterity is the Purdue Pegboard Assembly Task. This task was originally developed to test applicants for industrial jobs, and it has demonstrated its value in measuring a basic human ability which underlies several specific industrial tasks (Cronback, 1960, and Anastasi, 1961).

Tiffin and Asher (1948) in their study of the Purdue Pegboard present a compilation of scores from a variety of investigations. They have found the test-retest reliability of one trial on the assembly task to be .68. Subsequent analysis of the study data indicated that learning was not operating in the test conditions. They also studied the validity of the test for various representative types of jobs and have found validity coefficients as high as .76 for jobs described as "simple assembly of small parts".

These previous studies provide the basis for selecting the Purdue Pegboard Task as a device for measuring manual dexterity in the present investigation.

Grip Strength and Endurance

Grip strength is the ability to apply force by pulling the fingers simultaneously toward the palm of the hand. Holding a force in this particular manner involves grip endurance. The hand dynamometer and ergograph are standard devices for measuring grip strength.

Tuttle, Janney and Thompson (1950),in their study of strength and endurance, have found the maximum grip strength of 200 university men to be approximately 110 pounds. Their study utilized a dynamometer with two handle parts which the subjects squeezed together. Movement of the handle parts activated a strain gauge, calibrated to record the maximum strength. Other studies by Fisher and Birren (1946, 1947) have found maximum grip strength to be approximately 125 pounds. The method they used was a dynamometer which required a known load to activate. Thus the load could be increased until the subjects could no longer activate the dynamometer.

Caldwell (1961, 1963, 1964) has conducted a series of studies associated with strength and endurance. To measure these factors, he used a dynamometer which activated a light when force applied to the dynamometer handle was below a certain level. The actual amount of loading is dependent upon the subject's ability to hold the dynamometer with a force just above the required level. Hunsicker and Donnelly (1955, in their review of strength measuring devices, have described an ergograph which was first used by Mosso in 1890. The basic difference between the ergograph and other dynamometers was that the ergograph had a cable attached to a known weight and was used for repetitive movements.

In reviewing previous studies of endurance, Caldwell (1963) delineates two methods of measurement:

(1) Variable force, constant time - a method introduced by Tuttle, et. al., (1950) in which an average force is determined from human subjects exerting a maximum force for a fixed time period; and

(2) Constant force, variable time - a method used by Rohmert (1960) and Caldwell (1963) in which human subjects hold a given percent of maximum strength for as long as possible, and the time held represents the endurance.

Perhaps the most important step in establishing the relationship between strength endurance and time is the Rohmert formula (Caldwell 1970). He has suggested that:

$$T_s = -90 + 126/P - 36/P^2 + 6/P^3$$

where -90 is a constant

T_s is maximum holding time in seconds (endurance)

P is the percentage of maximum strength

Additional data supporting the relationships in this formula have been provided by Caldwell (1961, 1964).

With regard to the present investigation these previous studies provide basis for the following decisions:

(1) Endurance shall be defined in terms of the maximum time a given load can be held.

(2) A given percentage of maximum endurance for holding a given force shall be the same percentage of the maximum time that force can be maintained.

(3) The Rohmert formula shall be used to derive endurance.

(4) The Mosso concept of strength movement (Hunsicker and Donnelly, 1955) will be adopted in the design of a grip loading device.

The most recent treatment of human strength and its measurement is that of Kroemer (1970). The above definitions adopted for use in the present study generally conform to Kroemer's formulations.

Recovery From Muscle Loading

No real guidelines for establishing a feasible time sampling interval sensitive to recovery from exercise are available in the literature. Cowan and Solandt (1938) used a minimum recovery period of fifteen minutes. Other studies, Davies and Neilson (1964), Hennigan (1969) and Young (1956), used recovery periods of several minutes. There are several reasons why these times are inappropriate for the present study. Two major reasons are: (1) complex physical exercises were used involving either several muscle groups or the full body, and (2) physiological measurements varying with time were employed rather than performance measurements.

Caldwell (1970) says:

"As you will see, there has been comparatively little work done on recovery from the effects of isometric 'work'. Of

> course one difficulty with this research is that recovery is extremely rapid during the initial phase-----."

This suggests a much shorter time span for recovery than was used in previous research. Since the time sampling interval is critical, a pilot study was conducted to provide a guideline for the present investigation. Details of this pilot study are presented in subsequent sections of this report.

CHAPTER III

METHOD

Apparatus

Pegboard: This consists of a standard Purdue Pegboard with a strip of numbered tape along side the holes to facilitate scoring. Arrows on the tape point to every other hole, indicating use of that hole. Figure 1 shows the pegboard as viewed by the subject.

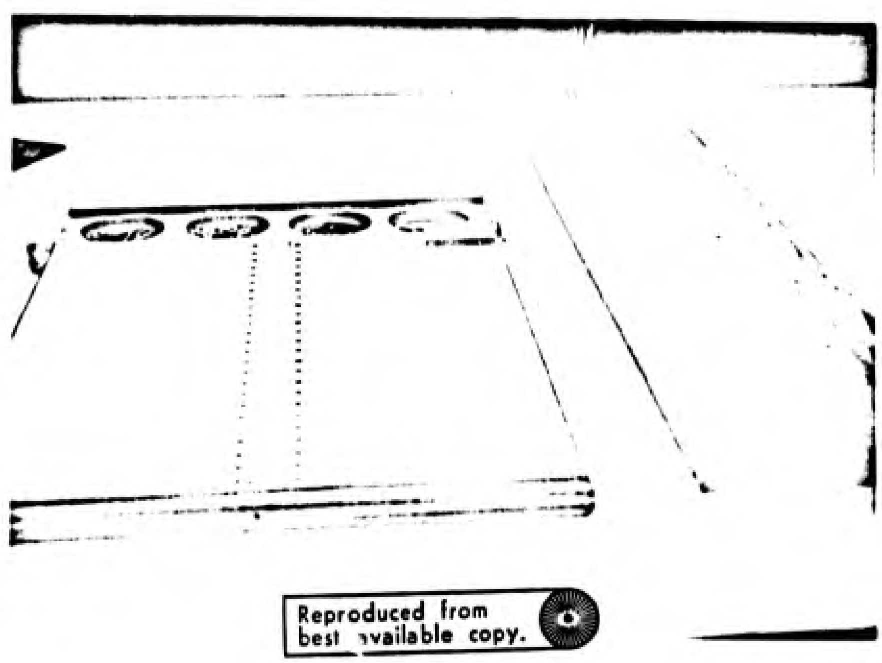

FIGURE 1 PURDUE PEGBOARD AND GRIP LOADING DEVICE AS VIEWED BY THE SUBJECT

Grip Loading Device: This consists of a two-part handle which the subjects hold together by gripping. One part of the handle is stationary and shaped to fit the human hand. The other is cylindrically

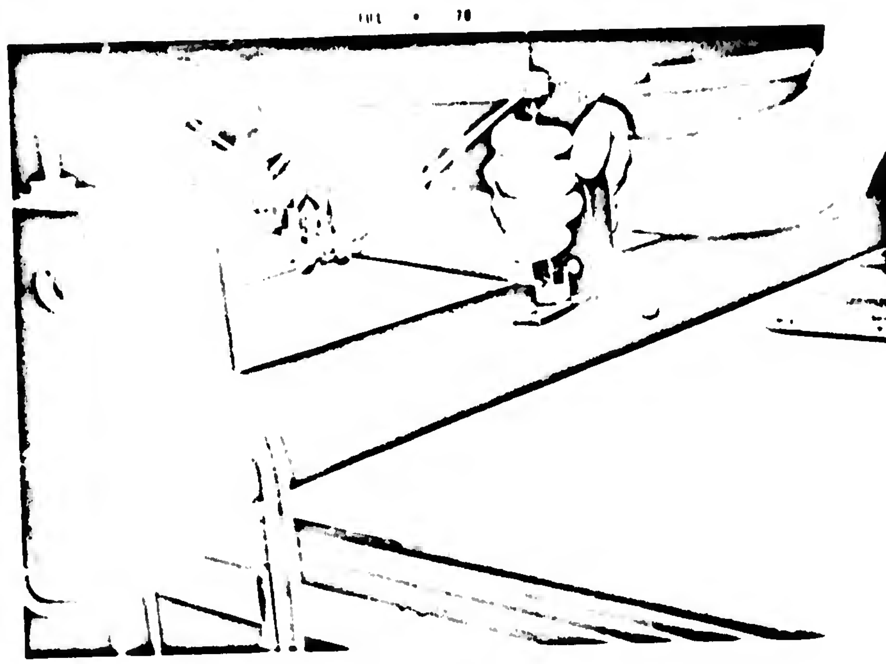

FIGURE 2 LOADING ON GRIP LOADING DEVICE

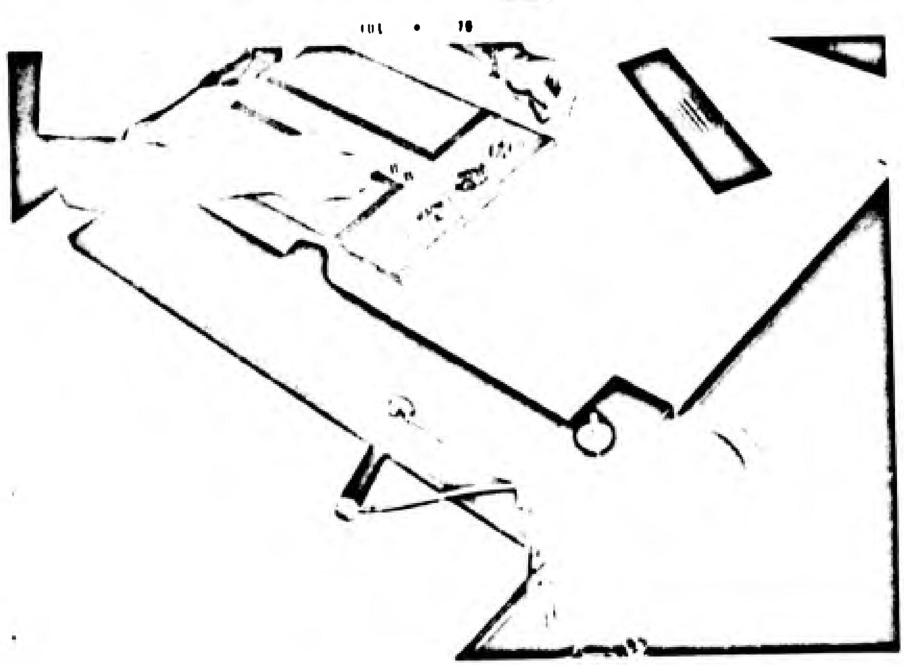

FIGURE 3 ASSEMBLIES BEING PLACED ON PURDUE PEGBOARD AND ARRANGEMENT OF APPARATUS

shaped, 7/8 inch in diameter by 5 1/2 inches long and is attached by means of a cable and pulley to barbell weights. These weights are suspended from the floor when the handle parts are held together.

Figures 1, 2, and 3 show the arrangement of the pegboard and grip loading device.

Timing Device: A standard wristwatch with a sweep second hand is used to measure endurance time and pegboard test performance.

Subjects

The subjects are ten male graduate students between the ages of twenty-two and twenty-eight. All are members of a system safety graduate training class and three are left-handed.

Procedure

Prior to actual conduct of the study, four criteria had to be established. These include (1) maximum strength of each subject; (2) the percentages of that maximum strength for loading each subject; (3) an appropriate sampling interval for examining recovery; and (4) endurance levels represented by the loadings. The first and third were established from pilot studies (Appendix A). The last criterion was determined using Item (2) in Rohmert's formula. Appendix B gives a table of values from this formula.

Table 1 identifies the study conditions. Column (1) shows there are nine conditions, and columns (2), (3), and (4) define for each condition the percentage of maximum strength, loading time and percentage of endurance respectively.

TABLE 1

CONDITIONS USED IN LOADING SUBJECTS

(1) Condition Number	(2) Percentage of Maximum Strength	(3) Time Loaded In Seconds	(4) Percentage of Maximum Endurance Represented
1	30	61	40
2	30	91	60
3	30	122	80
4	60	19	40
5	60	29	60
6	60	38	80
7	90	5.4	40
8	90	8.4	60
9	90	11	80

After receiving training with the pegboard, each subject is tested under the nine conditions of loading shown in Table 1. The testing order is random.

In order to avoid fatigue, a minimum of two hours is required between each test period. The testing took place between 8:00 a.m. and 12:00 noon and required a total of approximately two weeks to complete.

Each subject is given one practice trial lasting one minute on the Purdue Pegboard as a warm up at the beginning of each test period. The subject is then retested and scores are recorded at ten second intervals. These scores are used as the before loading scores. Next, the subject is loaded on the grip loading device in one of the nine loading conditions and immediately following the completion of the loading subject begins assembly task on the Purdue Pegboard. Two seconds are allowed for subject to prepare for the beginning of pegboard test. Instructions used in this phase of the test are given in Appendix C. These scores are again recorded at ten second intervals and are used as the after loading scores.

Measures and Analyses

Because of the brevity of the ten second recording interval, scores are recorded as the cumulative total. As mentioned earlier, a numbered strip of tape is included on the pegboard along side the column of holes. By using these numbers, a quick glance at the end of each ten second interval gives experimenter the correct total. Upon completion of test, these totals are broken down into incremental scores. Incremental scores represent the number of parts assembled during the corresponding ten second period. Subtraction of the after loading scores from the before loading scores gives a decrement, caused by the loading. The decrement values, called difference scores, are used as the basis for subsequent analysis and hypothesis testing. In testing difference scores, t-tests for differences are used. Other tests employ the conventional t-test for correlated measures.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the present study are summarized for discussion under three major headings - Decrement and Recovery, Decrement and Equivalent Levels of Endurance, and Decrement and Non-Equivalent Levels of Endurance. Details underlying these topics are discussed in the paragraphs which follow.

Decrement and Recovery

Two questions are important here. First, does loading under different levels of endurance result in decrements of manual dexterity, and secondly, what are the critical times associated with these decrements if they occur? To resolve these questions, subjects' manual dexterity performances are measured every 10 seconds during a one minute interval of work on the pegboard. Each subject's performance before loading is then compared with his performance after loading. Table 2 is a summary of these comparisons. This table is a matrix of t - values (paired observations) resulting from the before and after comparisons. Column (1) of this table contains the nine experimental conditions; Column (2) through (7) contain a breakdown of the six 10 second intervals, and the matrix cells contain associated t - values.

Table 2 clearly shows that each of the nine conditions of loading caused a significant decrement in the manual dexterity performances of the subjects. Furthermore, the decrements occur during the first 10

TABLE 2

t-VALUES FOR THE COMPARISON OF BEFORE AND AFTER LOADING SCORES (Critical Value for t is 1.83, df = 9)

(1) Condition Number	Time Inverval (seconds)					
	(2) 0-10	(3) 10-20	(4) 20-30	(5) 30-40	(6) 40-50	(7) 50-60
1	2.01	1.52	1.01	-1.34	0.77	-1.10
2	2.40	0.77	0.00	0.77	-0.54	-0.54
3	2.37	1.08	0.73	-0.86	1.34	-0.95
4	2.21	-1.64	-1.43	-0.23	0.95	-0.42
5	2.42	1.79	1.58	-0.20	0.95	0.00
6	2.47	1.55	0.69	-1.08	0.31	-0.36
7	2.01	0.54	-0.73	-1.08	-0.36	0.31
8	2.21	-1.20	-1.10	0.54	-1.34	0.51
9	2.54	0.00	-1.34	0.00	-0.86	0.79

seconds of performance only. Recovery from loading apparently takes place during the first ten seconds, and dexterity performance is no longer affected. One simple explanation for this finding is the simplicity of the task combined with the fact that the precise muscle groups underlying manual dexterity, as measured by the Purdue Pegboard, were not loaded as specifically as they might have been. It is suggested that a somewhat different loading device which requires greater finger strength would be more suitable in subsequent studies.

Decrement and Equivalent Levels of Endurance

In studying Rohmert's formula, it is apparent that equivalent levels of endurance can be developed in different ways. A review of Table 1 clearly focuses this fact. Column (4) of this table shows that conditions 1, 4, and 7 are identical, as are conditions 2, 5, and 8 and conditions 3, 6, and 9. However, each of the conditions within the three identical groupings are derived differently. It is easy to understand how this works by examining the variations in the requirements associated with percentages of maximum strength and loading time. Smaller percentages of maximum strength are exerted for longer periods of time and larger percentages are exerted for shorter times.

An important question, in this respect, is: does loading to equivalent levels of endurance, developed by varying strength and loading time, differentially affect manual dexterity performance? To resolve this question, performance decrements caused by endurance levels within each of the groupings are compared. Comparisons are made between 1, 4, and 7, all of which represent the 40% endurance level, and between conditions 2, 5, and 8 and 3, 6, and 9 which represent 60% and 80% endurance levels respectively. Table 3 contains a summary of these comparisons. Column (1), (2), and (3) identify the three endurance levels. Under each of these headings are two subcolumns showing conditions compared and corresponding t-values.

According to Table 3, loadings of equivalent endurance, although

TABLE 3

COMPARISON OF DECREMENT CAUSED BY EQUIVALENT LOADINGS
(Critical Value for t is 1.83, df = 9)

(1) 40% Endurance		(2) 60% Endurance		(3) 80% Endurance	
Conditions Compared	t-Value	Conditions Compared	t-Value	Conditions Compared	t-Value
1 vs 4	0.31	2 vs 5	1.07	3 vs 6	1.05
1 vs 7	0.00	2 vs 8	-0.10	3 vs 9	0.26
1 vs 7	-0.30	5 vs 8	-1.47	6 vs 9	-0.79

developed in different ways, do not differentially affect manual dexterity performance. Finding out that loadings of equivalent endurance levels affect performance in similar ways is, of course, no surprise. It is important, however, when one considers that these levels were determined a-priori from an existing equation relating strength, endurance and time. In this case the consistency and reliability of this equation is strengthened; but probably more important is the establishment of a data base to support its applicability to problems addressed by the present study, namely worker efficiency.

Decrement and Non-equivalent Levels of Endurance

The logical question to ask at this point is: do loadings of non-equivalent levels of endurance differentically affect manual dexterity performance? For these comparisons, performance scores resulting from the three equivalent conditions comprising each of endurance level of 40%, 60%, and 80% are grouped across subjects. These groups of scores are then compared across conditions of endurance. Table 4 is a summary of these comparisons. Column (1) in this table identifies each of the three comparisons, and Column (2) contains the resulting t-values.

TABLE 4

COMPARISON OF DECREMENT CAUSED BY NON-EQUIVALENT LOADINGS
(Critical Value of t is 1.83, df = 9)

(1) Conditions Compared	(2) t-Values
40% vs 60%	1.96
40% vs 80%	2.28
60% vs 80%	0.17

The t-values in Table 4 show that manual dexterity performance is differentially affected by non-equivalent endurance levels. Specifically, decrements caused by both the 60% and 80% levels are significantly larger than the 40% level. No difference exist between the 60% and 80% levels.

Another way to examine the effects of non-equivalent levels of endurance or manual dexterity concerns scale comparisons. One can conceive the existance of two scales underlying the conditions of this study. As can be seen in Figure 4, one of these scales is endurance and the other is decrement in worker efficiency resulting from endurance. The practical meaningfulness of the present study and similar studies depend upon establishing a relationship between these two scales.

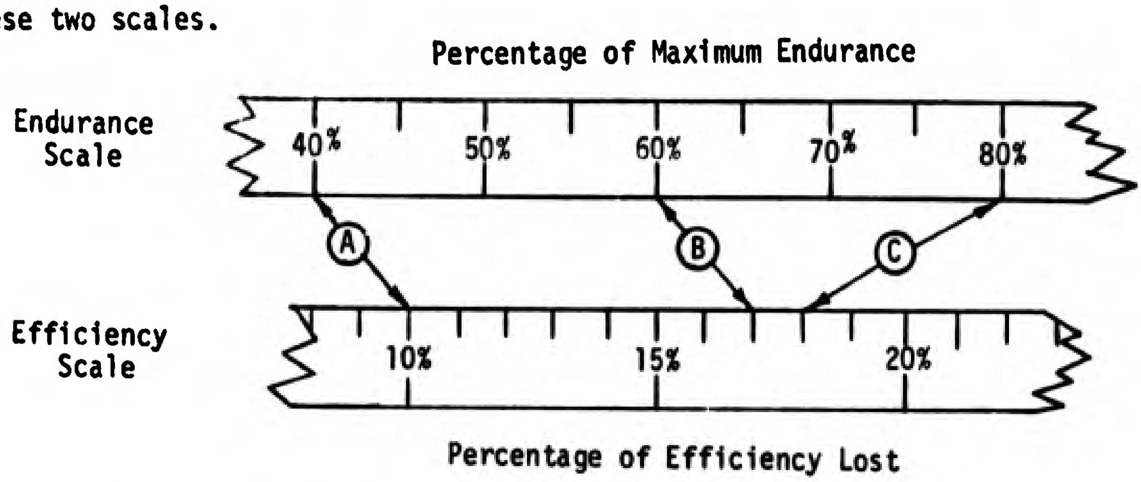

FIGURE 4 RELATIONSHIP BETWEEN ENDURANCE AND EFFICIENCY SCALES

From the results of the present study, a 40% increment on the endurance scale corresponds to a 10% decrement on the efficiency scale. In Figure 4, this is shown by arrow A. Arrows B and C show that increments of 60% and 80% endurances correspond to 17% and 18% decrements respectively. There is apparently a meaningful relationship between these two scales, however, it is not a one-to-one relationship. Further study is required to determine precisely the correlation between these two scales.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Results of the data analyses presented in the previous chapter provide support for each of the three study hypotheses. On the basis of this support, it is concluded that:

(1) Prior grip-loading causes subsequent decrement in manual dexterity performance on a Purdue Pegboard.

(2) Decrement in manual dexterity performance resulting from prior grip-loading occurs in the first ten seconds of work on the Purdue Pegboard.

(3) Decrements in manual dexterity,as measured by the Purdue Pegboard, can be predicted from known relationships between strength, endurance and time, as established in Rohmert's formula.

In addition to providing support for the study hypotheses, two other important findings are evident from the data analyses. These are labeled secondary conclusions and include:

(1) Loading to equivalent levels of endurance, although alternatively derived from Rohmert's formula, cause equivalent amounts of decrement in manual dexterity on the Purdue Pegboard. This finding provides additional support for validity of the formula.

(2) A hypothetical scale of worker efficiency, having units of percentage of efficiency lost, can be meaningfully related

to the endurance scale derived from the Rohmert formula.

A general summary conclusion for the present study is that production efficiency of a worker can potentially be related meaningfully to the biomechanical requirements of the task in which he is engaged. In this respect, the most important single implication of the present study relates, perhaps, to direction for future biomechanical research. Although in this particular investigation, the task is quite simple, the relationship between production efficiency and levels of endurance are evident. It is recommended, therefore, that a systematic program be planned and conducted to establish the total range of this relationship.

Recommendations for Further Study

This study utilizes a Purdue Pegboard and uses it to measure manual dexterity, and a restricted range of endurance. Other human abilities could be measured for subsequent study. More endurance levels could be employed which are representative of the entire range. Grip-holding strength is employed in this study, but many other types of loading could be used. Any isometric exercise should be applicable for loading using Rohmert's formula for endurance. It is anticipated that such a program would provide a useful data base for generalization to the industrial environment.

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APPENDIXES

Appendix A: **Pilot Studies**

Appendix B: **Table of Loading for Maximum Endurance**

Appendix C: **Test Instructions**

APPENDIX A

PILOT STUDIES

This appendix contains the two pilot studies which were run for the purpose of obtaining information needed prior to the main study. The first study consisted simply of ten practice trials run on the Purdue Pegboard, six in succession on the first day and four on the second. The instructions for each are given in Appendix C. The primary purpose of this study was to eliminate any learning which might contaminate the results. Scores were found to be significantly higher between the first and second trials. After the second trial there was a trend toward higher scores, but the improvement was not significant at a five percent level. Figure A shows the results of the ten practice trials. A second purpose of this pilot study was to determine the best

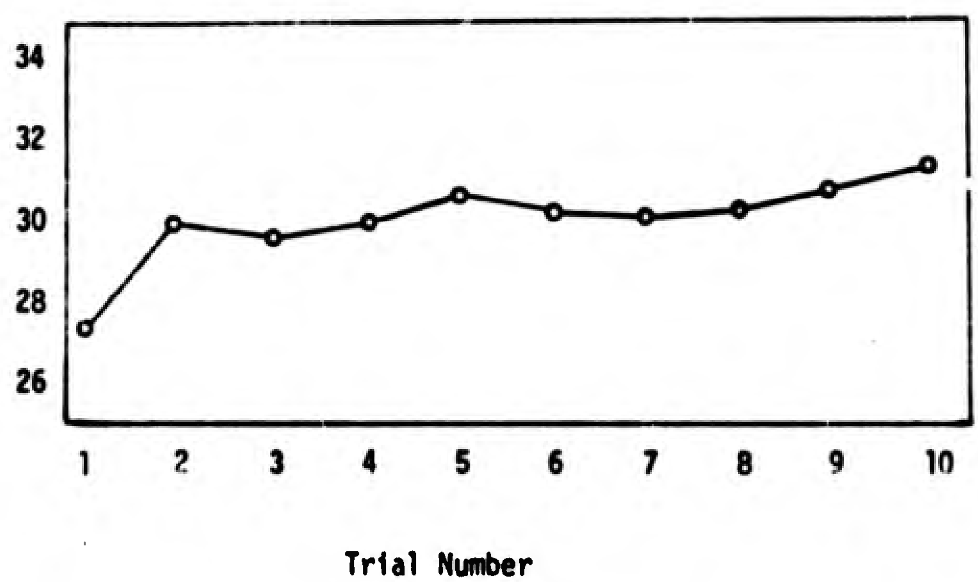

FIGURE A PRACTICE ON PURDUE PEGBOARD, RIGHT HAND ASSEMBLY TEST (10 subjects) time interval for recording scores. Various times were tried, and an interval of ten seconds was decided upon.

The purpose of the second pilot study was to establish the maximum load for each subject. This was done by estimating the maximum load which each subject could hold and asking the subject to hold that load for as long as possible (instructions are listed in Appendix C). Assuming that the time held represented his maximum endurance, the formula for endurance was used to calculate a table of values which in turn was used to establish a better estimate of the maximum load. (This table is given in Appendix B.) This process was repeated until the actual maximum load was found to be that which the subject could hold for six seconds.

Since fatigue prevented repetition of the process in succession, this pilot study took several days to complete. The maximum grip strength, as determined by this study, varied from 145 pounds to 195 pounds with a mean of 169 pounds. These data are somewhat higher than that found in the literature review (Chapter III). This is probably due to the fact that the strength as determined in the literature was strength involved in closing the hand, whereas in this study it was the strength to hold the hand closed.

APPENDIX B

TABLE OF LOADING FOR MAXIMUM ENDURANCE

This appendix contains a table of values derived from Rohmert's formula for endurance ($T_s = -90 + 126/P - 36/P^2 + 6/P^3$). Each combination of values represents maximum endurance.

TABLE B

LOADINGS REPRESENTING MAXIMUM ENDURANCE

Percentage of Maximum Strength (P)	Time in Seconds (T_s)	Percentage of Maximum Strength (P)	Time in Seconds (T_s)
0.01	5652511.0	0.30	152.2
0.02	666210.1	0.31	143.2
0.03	186332.3	0.32	135.2
0.04	74310.0	0.33	128.1
0.05	36030.0	0.34	121.8
0.06	19787.7	0.35	116.0
0.07	11855.7	0.36	110.8
0.08	7578.7	0.37	106.0
0.09	5096.0	0.38	101.6
0.10	3570.0	0.39	97.5
0.11	2588.1	0.40	93.7
0.12	1932.2	0.41	90.2
0.13	1480.0	0.42	86.9
0.14	1159.8	0.43	83.7
0.15	927.7	0.44	80.8
0.16	756.0	0.45	78.0
0.17	626.7	0.46	75.4
0.18	527.6	0.47	72.9
0.19	450.6	0.48	70.5
0.20	390.0	0.49	68.2
0.21	341.5	0.50	66.0
0.22	302.4	0.51	63.8
0.23	270.4	0.52	61.8
0.24	244.0	0.53	59.8
0.25	222.0	0.54	57.9
0.26	203.4	0.55	56.1
0.27	187.6	0.56	54.3
0.28	174.1	0.57	52.6
0.29	162.4	0.58	50.9

Percentage of Maximum Strength (P)	Time in Seconds (T_s)	Percentage of Maximum Strength (P)	Time in Seconds (T_s)
0.59	49.3	0.84	19.1
0.60	47.7	0.85	18.1
0.61	46.2	0.86	17.2
0.62	44.7	0.87	16.3
0.63	43.2	0.88	15.4
0.64	41.8	0.89	14.6
0.65	40.4	0.90	13.7
0.66	39.1	0.91	12.9
0.67	37.8	0.92	12.1
0.68	36.5	0.93	11.3
0.69	35.2	0.94	10.5
0.70	34.0	0.95	9.7
0.71	32.8	0.96	8.9
0.72	31.6	0.97	8.2
0.73	30.4	0.98	7.4
0.74	29.3	0.99	6.7
0.75	38.2	1.00	6.0
0.76	27.1	1.01	5.2
0.77	26.0	1.02	4.5
0.78	25.0	1.03	3.8
0.79	23.9	1.04	3.2
0.80	22.9	1.05	2.5
0.81	21.9	1.06	1.8
0.82	21.0	1.07	1.2
0.83	20.0	1.08	0.5

APPENDIX C

TEST INSTRUCTIONS

This appendix contains instructions for the tests given in the pilot study. The first two sets of instructions were read to the subjects prior to the tests in the respective pilot study. The third set of instructions was used prior to testing in the main study.

Instructions For Purdue Pegboard Assembly Test

This test is the right-handed assembly test. An assembly consists of a pin, washer, collar, and washer, in that order (demonstrate). Assemblies should be placed in every other hole in the right-hand column, as designated by the arrows. If you drop any parts, complete the assembly as quickly as possible, either with the dropped part or another part from the tray, and then continue.

You will begin the test on the command of "get ready - go". On the command of "get ready", place your right forearm on the board or on the table with your hand near the trays. On the command of "go", begin. You will have one minute to complete the test; go as fast as possible.

Are there any questions?

Instructions For Determining Maximum Strength

This test is designed to determine your maximum grip strength.

Place your right forearm on the board with your hand on the gripping device and your fingers around the handle parts. When I say ready, I will release the weight attached to the handle and you will hold the weight as long as possible by gripping. Hold all questions about the amount of weight until the end and do not look under the table at the weights. Are there any other questions?

Instructions For Loading On the Grip Loader Prior To Pegboard Test

This test will consist first of muscular loading on the grip loader and then the Purdue Pegboard right-hand assembly task.

Loading will be accomplished in the same manner as previously used on the test for maximum strength with different loads and different loading times. You should not be taxed beyond your strength, so do not drop the load until you are told to do so, if you can avoid it.

The transition from the loading device to the pegboard will be accomplished as follows: the command of "get ready" will be given approximately two seconds prior to the command "drop"; on the command "drop", drop the load by straightening your fingers and immediately place your right forearm on the pegboard or table with your hand near the trays and get ready to begin the pegboard test; two seconds following the command "drop", you will be given the command "go" and will begin the assembly task as before.

Hold all questions about the weight and time of loading until the end of the test.

Are there any other questions?