

A verification study of the psychophysical method for upper extremity work
by Michael L Willis

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Industrial and Management Engineering
Montana State University
© Copyright by Michael L Willis (1994)

Abstract:
The psychophysical method of adjustment used in determining upper extremity work parameters was evaluated for a simulated sheet metal pilot hole drilling task. The experiment consisted of 6 subjects. Subjects applied 12 lbs. of force to a load cell for a duration of 1 second at a frequency they determined based on the instructions they were given (psychophysical method of adjustment).

The frequency adjustment period lasted 20 minutes at which time the frequency was maintained for an additional 5 minutes. This sequence was repeated 4 times consecutively on 4 separate occasions (16 total bouts).

Heart rate (HR), maximum acceptable frequency (MAF) and rating of perceived exertion (RPE) were recorded for each sequence. Data was evaluated using ANOVA techniques and correlation matrices to determine the reliability and the HR/MAF and HR/RPE relationships.

The study found that the MAF determined in a 25 minute psychophysical bout was a reliable prediction of the MAF that was selected at the conclusion of 4-25 minute bouts. The overall MAF and the mean MAF for Week 2 were compared to published data and no significant difference was found. Based on these results it was concluded that the psychophysical method can reliably be used to determine upper extremity task parameters.

Based on the fact that factors which were not controlled in this study can affect HR, this study was inconclusive in determining the relationship between HR and MAF in using the psychophysical method of adjustment for upper extremity work to determine physiological demands caused by the work load. However, evidence was present that suggests subjects were able to perceive the overall demand and adjust their workload accordingly.

The data also showed that subjects were unable to assign verbal anchors to the physiological effort they were exerting. This may be caused by the difference in testing criteria used in RPE and method of adjustment studies.

A VERIFICATION STUDY OF THE PSYCHOPHYSICAL METHOD FOR UPPER EXTREMITY WORK

by

Michael L. Willis

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Industrial and Management Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 1994

N378
W679

APPROVAL

of a thesis submitted by

Michael L. Willis

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style and consistency, and is ready for submission to the College of Graduate Studies.

5/5/94
Date

Chairperson, Graduate Committee

Approved for the Major Department

5/5/94
Date

Head, Major Department

Approved for the College of Graduate Studies

5/25/94
Date

Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a masters degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature Michael L. Wellis

Date 5/5/94

ACKNOWLEDGEMENTS

Thanks go out to Dr. Don Boyd and Dr. Paul Schillings for their guidance in developing the experimental design for this study. Special thanks go to Dr. Robert Marley for his advice throughout my graduate studies.

TABLE OF CONTENTS

Chapter		Page
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	4
	Psychophysical History	4
	Classical Psychophysical Methods	5
	Method of Constant Stimuli	5
	Method of Limits	7
	Method of Adjustment	7
	Psychophysical Parameters, Problems and Methods	8
	Psychophysical Research	10
	Borg Scale	12
	Lower Extremity Research	13
	Upper Extremity Research	18
3.	OBJECTIVES AND RATIONALE	23
4.	METHODS AND PROCEDURES	25
	Subjects	25
	Equipment	27
	Procedures	30
	Anthropometric and Strength Measures	30
	Simulated Drilling Task	32
	Familiarization Period	33
	Psychophysical Frequency Determination	34
	Experimental Design	35
5.	RESULTS AND DISCUSSION	39
	Subjects	39
	Analysis	40
	Psychophysical Reliability	42
	HR/MAF Relationship	47
	HR Analysis	49
	RPE/HR Relationship	54
	RPE Analysis	56

TABLE OF CONTENTS - Continued

Chapter	Page
6. CONCLUSIONS AND RECOMMENDATIONS	62
Conclusions	62
Recommendations	64
REFERENCES CITED	66
References	67
APPENDICES	73
Appendix A - Scales, Forms and Questionnaires	74
Borg Scale	75
CTD/Medical History Screen	76
Informed Consent	77
Subject Instructions	79
Data Collection Form	80
APPENDIX B - Subject Analysis	82
Mean Test for Stature	83
Mean Test for Elbow Height	84
Mean Test for Weight	84
Mean Test for Grip Strength	85
Mean Test for Pinch Strength	85
Subject Measures Correlation Matrix	86
Mean Test for Stature Between Groups	86
Mean Test for Elbow Height Between Groups	87
Mean Test for Weight Between Groups	87
Mean Test for Grip Strength Between Groups	88
Mean Test for Pinch Strength Between Groups	88
APPENDIX C - Dependent Variable Values	89
APPENDIX D - Reliability Data	93
% Difference Between Weeks for MAF	94
Test Between Overall and Subject Variances	94
Pooled Variance	94
Weighted Mean	95
Confidence Interval	95
Tukey Test on Bout for MAF	95
Mean Test for Days of Testing	96
Mean Test Between Published and Overall MAF	96
Mean Test Between Published and Week 1 MAF	97
Mean Test Between Published and Week 2 MAF	97
APPENDIX E - HR/MAF Relationship Data	98
Pearson Correlation Matrix for HR and MAF	99
Individual HR by MAF Correlation Matrices	99
Individual HR by MAF Correlations for each Testing Period	100

TABLE OF CONTENTS - Continued

Chapter	Page
APPENDIX F - HR Analysis Data	103
Tukey Test on Week*Time for HR	104
Mean HR Values for Week*Time	104
Tukey Test on Group*Week*Time for HR	105
Mean HR Values for Group*Week*Time	105
APPENDIX G - RPE/HR Relationship Data	106
Pearson Correlation Matrix for HR and MAF	107
Individual HR by RPE Correlation Matrices	107
Individual HR by RPE Correlations for each Testing Period	108
APPENDIX H - RPE Analysis Data	111
Tukey Test on Group*Week for RPE	112
Mean RPE Values for Group*Week	112
Tukey Test on Group*Time for RPE	113
Mean RPE Values for Group*Time	113

LIST OF TABLES

Table		Page
1.	Psychophysical Parameters	8
2.	Psychophysical Problems and Methods	9
3.	Representative Exponents of the Power Function	11
4.	MAF Per Minute in Mean(STD) at Various Wrist Postures for Males and Females	22
5.	Subject Data	26
6.	Variable List	36
7.	Experimental Design Layout for RPE, HR and MAF	38
8.	Anticipated ANOVA	38
9.	Subject Descriptive Statistics	39
10.	Means and (Standard Deviations) for MAF	41
11.	Means and (Standard Deviations) for RPE	42
12.	Means and (Standard Deviations) for HR	42
13.	MAF ANOVA	44
14.	HR ANOVA	51
15.	RPE ANOVA	58
16.	Random Numbers	81
17.	Subject Data	83
18.	Raw Data	90

LIST OF FIGURES

Figure		Page
1.	Percent "Most Tired" Among Manual Workers Ages 20 to 35	17
2.	Graphical Representation of Equation 3	19
3.	Phalen's Test	26
4.	Simulated Work Station (Side View)	27
5.	Simulated Work Station (Front View)	28
6.	Neutral Positions of the Wrist	31
7.	Simulated Drilling Posture	31
8.	Residual Plot for MAF	43
9.	Normal Score Plot for MAF	43
10.	Bout by MAF	45
11.	Mean MAF Comparisons to Published Data	47
12.	Subject HR/MAF Comparison	48
13.	Residual Plot for HR	50
14.	Probability Plot for HR	50
15.	Week*Time Interaction for HR	52
16.	Time*Week Interaction for HR	52
17.	Week*Group*Time Interaction for HR	53
18.	Subject HR/RPE Comparison	55
19.	Residual Plot for RPE	57
20.	Normal Scores Plot for RPE	57

LIST OF FIGURES - Continued

Figure Page

21. Group*Week Interaction for RPE 59

22. Week*Group Interaction for RPE 59

23. Group*Time Interaction for RPE 60

24. Time*Group Interaction for RPE 61

25. Fifteen Point Borg RPE Scale 75

26. Data Collection Form 80

ABSTRACT

The psychophysical method of adjustment used in determining upper extremity work parameters was evaluated for a simulated sheet metal pilot hole drilling task. The experiment consisted of 6 subjects. Subjects applied 12 lbs. of force to a load cell for a duration of 1 second at a frequency they determined based on the instructions they were given (psychophysical method of adjustment).

The frequency adjustment period lasted 20 minutes at which time the frequency was maintained for an additional 5 minutes. This sequence was repeated 4 times consecutively on 4 separate occasions (16 total bouts).

Heart rate (HR), maximum acceptable frequency (MAF) and rating of perceived exertion (RPE) were recorded for each sequence. Data was evaluated using ANOVA techniques and correlation matrices to determine the reliability and the HR/MAF and HR/RPE relationships.

The study found that the MAF determined in a 25 minute psychophysical bout was a reliable prediction of the MAF that was selected at the conclusion of 4-25 minute bouts. The overall MAF and the mean MAF for Week 2 were compared to published data and no significant difference was found. Based on these results it was concluded that the psychophysical method can reliably be used to determine upper extremity task parameters.

Based on the fact that factors which were not controlled in this study can affect HR, this study was inconclusive in determining the relationship between HR and MAF in using the psychophysical method of adjustment for upper extremity work to determine physiological demands caused by the work load. However, evidence was present that suggests subjects were able to perceive the overall demand and adjust their workload accordingly.

The data also showed that subjects were unable to assign verbal anchors to the physiological effort they were exerting. This may be caused by the difference in testing criteria used in RPE and method of adjustment studies.

CHAPTER 1

INTRODUCTION

Perceived exertion is a privately experienced subjective reaction to physical work that can only be measured indirectly through the use of self-report techniques. The applicability of subjective symptoms as criteria in the assessment of upper extremity work depends on elements which affect the reliability and validity of measurement. These elements include: (1) the type of subjective reaction observed, (2) the way the reaction is observed and recorded, (3) the degree to which the reaction varies in different work operations, (4) the reaction's correlation with work intensity and work performance and (5) the reaction's correlation with the physiological and neurological events (Gamberale 1985).

Perceived exertion can be interpreted as the "summing up" of the influences from all structures under stress during work. This perception has a psychological validity and reflects the interplay between the requirements of the job and the individual's capacity (Gamberale 1985).

Kroemer (1989) defines cumulative trauma disorders (CTD) as:

> "Syndromes characterized by discomfort, impairment, disability or persistent pain in joints, muscles, tendons and other soft tissues, with or without physical manifestations, caused or aggravated by repetitive motions including vibrations, sustained or constrained postures, and forceful movements at work or leisure."

One form of CTD is carpal tunnel syndrome (CTS). CTS is attributed to compression of the median nerve as it passes through the carpal canal of the wrist (Armstrong and Chaffin 1979). This compression is associated with repeated use of the fingers and hands, combined with force (Feldman et al. 1983).

Krawezyk et al. (1993) reports that in 1981 the number of CTD was 23,000 which accounted for 18% of all occupational illnesses. By 1991 these numbers had increased to 223,600 new cases accounting for 61% of all occupational illnesses. Tanaka et al. (1988) reported that CTD accounted for 48% of all workers' compensation claims in one particular state. Fernandez et al. (1990) reports that severe cases of CTS which require surgery, compensation and disability claims can cost in the range of $30,000 to $60,000.

Due to the increased occurrence and high cost of CTD, specifically CTS, psychophysical techniques have been used to determine work loads and frequencies which reduce the risk of CTD occurring. The use of this technique assumes that the worker is able to accurately indicate the highest workload he can tolerate and that this workload will not lead to injuries (Gamberale 1985). The use of psychophysical methods are

justified by the fact that there are no widely accepted biomechanical or psychophysical models for determining repetitive manual work guidelines for multiple factors (Tanaka and McGlothlin 1993).

This study attempted to determine the reliability of and the associations between heart rate (HR) and maximum acceptable frequency (MAF) and HR and rating of perceived exertion (RPE) when using the psychophysical method of adjustment in determining work parameters for the upper extremity. A drilling task was simulated in which subjects determined the frequency at which they were willing to work based on their perceived exertion.

Psychophysical reliability was evaluated across consecutive trials, times of day, two-week intervals and order of testing. The relationships between HR and MAF and HR and RPE were determined through the use of correlation matrices.

CHAPTER 2

LITERATURE REVIEW

Psychophysical History

Wilhelm Wundt founded the first laboratory directed exclusively toward work in the field of experimental psychology as an independent science in Leipzig in 1879. His work and that of others in the field evolved from the British schools of philosophy which had established the idea of the senses as the key to human understanding (Gescheider 1985).

Gescheider (1985) claims that the most important historical antecedent of experimental psychology was psychophysics. Psychophysics is the scientific study of the relationship between stimulus and sensation.

The field of psychophysics involves the theory of signal detection and methods for directly scaling sensory magnitude. The inclusion of these two areas into the field has broadened the applicability of psychophysics to sensory processes, memory, learning, social behavior and esthetics (Gescheider 1985).

Classical Psychophysical Methods

Presenting a stimulus to an observer and asking them to report their perception is the basic procedure for measuring psychophysical thresholds. However, the threshold cannot be defined as an absolute because biological systems are variable. Therefore, thresholds must be specified as statistical values (Gescheider 1985).

As reported by Gescheider (1985), Fechner (1860) recognized the statistical nature of thresholds and developed three methods for measuring them: the methods of constant stimuli, limits and adjustment.

Two types of thresholds, absolute and difference, can be measured using these methods. An absolute threshold is the intensity range in which a stimulus becomes detectable on ascending trials and undetectable on descending trials. A difference threshold is the intensity range in which a stimulus is perceived to be equal to a fixed intensity stimulus.

These methods were described in detail by Gescheider (1985) and are summarized as follows.

Method of Constant Stimuli

The method of constant stimuli is a procedure in which the same stimuli continuum on different levels of intensity is presented throughout an experiment. At the low end of the stimulus range is a stimulus which can almost never be

detected, and at the upper end a stimulus which can almost always be detected.

During an experiment, a count of the number of times each stimulus level is and is not detected is kept. The proportion of detected responses is calculated and a graph *(psychometric function)* is constructed. The absolute threshold is the stimulus level for which the proportion of detections is 0.5.

To determine a difference threshold using this method, one stimulus value is fixed throughout the experiment *(standard stimulus)* and another is changed from trial to trial *(comparison stimulus)*. The comparison stimulus is randomly presented at levels less than, greater than and equal to the standard stimulus. The observer's task is to determine which stimulus produces a sensation of greater magnitude.

Up to 9 levels of the comparison stimulus can be used. These levels are selected such that the stimulus of greatest magnitude is almost always evaluated as being greater than the standard, and such that the stimulus of least magnitude is almost always evaluated as being less than the standard.

When no difference can be perceived, the proportions of greater and lesser responses are expected to be approximately equal. On the psychometric function this 0.5 point is called the *point of subjective equality*. This point represents the comparison stimulus level which is perceived subjectively as equal to the standard stimulus over a large number of trials.

Method of Limits

The method of limits is a procedure in which the experimenter presents a stimulus distinctly above or below the threshold. The absolute threshold is approached by adjusting the stimulus intensity until the sensation boundary is reached. The stimulus intensity may be adjusted in either direction. Each sensation boundary observed can be considered a threshold estimation. The absolute threshold is determined as the average of these estimations.

The two constant errors of habituation and expectation may influence results obtained using this method. Avoiding long trial series, varying the starting points of successive series, preliminary training and careful instructions may help to reduce the effects of these two tendencies.

In determining difference thresholds using this method, standard and comparison stimuli are presented in pairs on successive trials. The comparison stimulus is adjusted in the direction of the standard stimulus until they are perceived as being equal. The ascending and descending transition points where equality is first perceived are termed as the *lower limen* and *upper limen* respectively. The *interval of uncertainty* is the difference between these two values.

Method of Adjustment

The method of adjustment is a procedure in which the subject changes the stimulus necessary to measure a threshold. The procedure calls for setting the stimulus intensity level

either far above or far below the threshold. The subject then adjusts the stimulus intensity to the threshold level. Affording this large amount of active participation to the subject may prevent boredom and increase performance.

Several ascending and descending trials are generally performed with the absolute threshold being the mean. The stimulus intensity is usually a continuous variable.

Difference thresholds are determined using this method by allowing the subject to adjust a comparison stimulus until it is equal to a standard stimulus. This is done in a similar fashion to finding previously mentioned difference thresholds, however, the subject now controls the comparison stimulus adjustment.

Psychophysical Parameters, Problems and Methods

Psychophysics tries to quantify the functional relationship between stimulus and response: R=f(S). This function is affected by three classes of parameters: task, stimuli presentation and the statistical measure used for description. These classes and their subdivisions are presented in Table 1 (Stevens 1958).

Table 1. Psychophysical Parameters.

Task observer is to judge	Stimulus arrangement	Statistical measure
C Classification	F Fixed	L Measure of location (central tendency)
O Order	A Adjustable	V Measure of variability or confusion
I Intervals		
R Ratios		
M Magnitudes		

Source: Stevens (1958)

Common psychophysical problems and the typical methods used in their solution are listed in Table 2. These problem-method pairings are not intended to be exhaustive or optimal but illustrative of commonly used procedures (Stevens 1958).

Table 2. Psychophysical Problems and Methods.

I. To determine nominal scales	
a. Absolute thresholds	
1. Single stimuli	CFL
2. Counting	CFL
3. Forced location (forced choice)	CFL
4. Adjustment	CAL
5. Limits	CAL
6. Tracking	CAL
7. Staircase (up-and-down)	CFL
b. Resolving power or differential sensitivity	
1. Adjustment (average error)	CAV
2. Tracking	CAV-OAV-CAL
3. Constant stimuli	OFV
4. Single stimuli	IFV-OFV
5. ABX	CFV
6. Forced location	CFL
7. Quantal increments	CFL
c. Equation of magnitudes	
1. Adjustment	CAL
2. Constant stimuli	CFL-OFL
3. Tracking	CAL-OAL
4. Staircase (up-and-down)	CFL-OFL
d. Identification	
1. Single stimuli	CFV
II. To determine ordinal scales	
1. Pair comparison	OFL
2. Rank order (order of merit)	OFL
3. Rating scale	OFL-IFL
4. Single stimuli	CFV
III. To determine interval scales	
1. Equisection (bisection)	IAL-IFL
2. Interval estimation	IFL
3. Category rating (equal intervals)	IFL
4. Category production	IAL
5. Pair comparison	OFV
6. Rank order	OFV
7. Successive categories	IFV
8. Successive intervals	IFV
IV. To determine logarithmic interval scales	
1. Pair comparison	OFV
2. Ratio matching	RAL-RFL
V. To determine ratio scales	
1. Ratio estimation	RFL
2. Ratio production (fractionation, multiplication)	RAL-RFL
3. Magnitude estimation	MFL
4. Magnitude production	MAL

Note: The capital letters after each method refer to the psychophysical parameters in Table 1. Alternative procedures under a given method are indicated by multiple sets of letters. Source: Stevens (1958)

As can be seen, psychophysical problems may be regarded as scale construction problems. The nominal scale is the most general type of scale and involves only classification

with no ordering. Ordinal scales are used for setting perceptions in a rank order with respect to some aspect or attribute. Interval scales involve the development of equal interval scales on a psychological continuum. Logarithmic interval scales attempt to scale prothetic continuum into equal intervals in logarithmic terms based on the possibility that discriminal dispersion increases proportionally to psychological magnitude. Ratio scales are created on a perceptual continuum (Stevens 1958).

Psychophysical Research

Stevens (1986) concluded that the magnitude of a sensation grows as a power function of the stimulus magnitude by the formula:

$$\psi = \kappa\phi^{\beta} \qquad (1)$$

where: ψ = sensation magnitude
ϕ = stimulus magnitude
κ = constant which depends on the units of measurement
β = depends on the sensory continuum

This power law has been shown to hold under many circumstances. Several of these stimulus conditions are listed with their associated exponential value in Table 3.

The power function demonstrates that a constant percentage change in the stimulus produces a constant percentage change in the sensed effect. The graph of the power function plotted in log-log coordinates becomes a

straight line with the exponent, β, as the slope (Stevens 1986).

$$\log\psi = \beta\log\phi + \log\kappa \qquad (2)$$

Table 3. Representative Exponents of the Power Function.

Continuum	Measured exponent	Stimulus condition
Loudness	0.67	Sound pressure of 3000-hertz tone
Vibration	0.95	Amplitude of 60 hertz on finger
Vibration	0.60	Amplitude of 250 hertz on finger
Brightness	0.33	5° Target in dark
Brightness	0.50	Point source
Brightness	0.50	Brief flash
Brightness	1.00	Point source briefly flashed
Lightness	1.20	Reflectance of gray papers
Visual length	1.00	Projected line
Visual area	0.70	Projected square
Redness (saturation)	1.70	Red-gray mixture
Taste	1.30	Sucrose
Taste	1.40	Salt
Taste	0.80	Saccharine
Smell	0.60	Heptane
Cold	1.00	Metal contact on arm
Warmth	1.60	Metal contact on arm
Warmth	1.30	Irradiation of skin, small area
Warmth	0.70	Irradiation of skin, large area
Discomfort, cold	1.70	Whole body irradiation
Discomfort, warm	0.70	Whole body irradiation
Thermal pain	1.00	Radiant heat on skin
Tactual roughness	1.50	Rubbing emery cloths
Tactual hardness	0.80	Squeezing rubber
Finger span	1.30	Thickness of blocks
Pressure on palm	1.10	Static force on skin
Muscle force	1.70	Static contractions.
Heaviness	1.45	Lifting weights
Viscosity	0.42	Stirring silicone fluids
Electric shock	3.50	Current through fingers
Vocal effort	1.10	Vocal sound pressure
Angular acceleration	1.40	5-Second rotation
Duration	1.10	White noise stimuli

Source: Stevens (1986).

Borg Scale

Perceived exertion is defined by Borg (1962) as "The perception that makes the subject respond to the stimulus in accordance with the given psychophysical method and the instructions." Since man reacts to stimuli as he perceives it and not as it "really is", the relationship between objective and subjective measurements of physical stress is important (Borg 1970).

A simple scale for rating perceived exertion (RPE) was constructed by Borg (1970) to measure this relationship (Figure 25 in Appendix A). The subject is instructed to rate his degree of exertion based on his perception's correlation to the scale's verbal anchors.

This RPE scale was constructed such that the HR of a normal, healthy, middle-aged man can be predicted by the formula: RPE X 10 = HR. Borg (1962) found correlations between RPE and HR to be as high as r = 0.85. This relationship is fairly accurate for medium physical stress intensities, but it should not be taken too literally (Borg 1971).

Borg (1970) also found that physical work capacity declines with age but that HR does not at a given load. However, RPE values increase with age for the same work load. This is explained by the fact that maximal HR decreases with age. Therefore, RPE gives a better estimation of physical stress with age than does HR.

Several physiological parameters are linked to metabolic demand and the impact of relative aerobic power as a perceptual cue is mediated by other more readily monitored responses. Ventilation and respiration provide one source of sensory information for the perception of effort. The muscular discomfort which typically accompanies lactate accumulation is a source of sensory input which is readily available to conscious awareness (Mihevic 1981).

Modifying variables for the task response, such as intensity, duration, frequency, modality and response time suggests that multiple sensory inputs of local and central origin are integrated and weighed by the subject to arrive at an evaluation of overall perceived exertion (Mihevic 1981). The overall RPE integrates these signals elicited from the working muscles and joints, the central cardiovascular and respiratory functions and the central nervous system to give the single best indicator of the degree of physical strain (Borg 1982).

Lower Extremity Research

Considerable focus has been given to the determination of population materials handling capacities using the psychophysical approach. Manual lifting has been linked to most back injuries, therefore, more research has been conducted in this area than others (Ayoub 1987).

Two classes of models are used by researchers which address lifting activities: (1) Capacity Modeling which

predicts lifting capacities using the worker, task and environmental characteristics and is divided into psychophysical and physiological models. (2) Biomechanical stress modeling which estimates the reactive forces and torques at various joints using Newtonian mechanics (Ayoub et al. 1980).

The psychophysical approach has been used to determine lifting capacities through subjects quantifying their subjective tolerances to lifting stresses in several studies (Ljungberg et al. 1982, Mital 1983, Foreman et al. 1984, Griffin et al. 1984, Karwowski and Ayoub 1984, Legg and Myles 1985, Karwowski and Yates 1986, Mital 1986, Mital et al. 1987, Fernandez and Ayoub 1988, Fernandez et al. 1991).

Several of these studies have used physiological and psychophysical methods in conjunction in order to determine the reliability and validity of the psychophysical method. Legg and Myles (1985) found that with good subject cooperation and firm experimental control, the psychophysical method can identify loads that soldiers can lift repetitively for an 8-hour workday without metabolic, cardiovascular or subjective fatigue.

An experiment was conducted in which subjects estimated a work load they could perform for 8 hours in a 25-minute period. Subjects performed the task for 8 hours starting at the estimated load but were allowed to make load adjustments. The final load averaged 85.4% of the estimated load.

The subjects also attempted to perform the task for an 8-hour period at the estimated load without making adjustments at frequencies of 2 and 8 lifts/minute. However, not all of the subjects were physically able to complete the 8-hour, 8-lifts/minute, thus, indicating that the psychophysical approach is valid for measuring lifting capacities at low frequencies but overestimates the lifting capacity at high frequencies (Fernandez et al. 1991).

Karwowski and Ayoub (1984) concluded that loads determined by the psychophysical method of adjustment in a 40-minute period at frequencies of 9 and 12 lifts/minute resulted in the subjects exceeding recommended levels for aerobic expenditure and HR for an 8-hour day.

Similar studies also concluded that psychophysics overestimates the maximum acceptable weight of lift for high frequency tasks (Ciriello and Snook 1983, Mital 1983).

Karwowski and Yates (1986) distinguished the difference between the high and low lifting frequencies, at which the psychophysical method is reliable, to be 6-lifts/minute.

Karwowski (1983) proposed a fuzzy set model based on the hypothesis that combining the acceptability of the physiological and biomechanical stress should lead to an overall measure of the lifting task acceptability, expressed by the acceptability of the psychophysical stress. His results confirmed his hypothesis.

Ljungberg et al. (1982) found that psychophysical ratings were significantly higher for heavier versus lighter weights in horizontal lifting.

Thompson and Chaffin (1993) evaluated the relationship between the psychophysical and biomechanical approaches and concluded that back stresses are not well perceived at very low frequencies based on RPE data.

Gamberale et al. (1987) unintentionally discovered the sensitivity of psychophysical results to the instructions subjects are given during a lifting task. Two instructors conducted the experiment. One reminded the subjects during the course of the task to adjust the workload if they felt it was necessary. The results showed a significant difference ($p < 0.01$) between the two groups.

Foreman et al. (1984) attributed differences in acceptable isometric strength between two groups to minor differences in the instructions given.

Griffith et al. (1950) studied the hypothesis that employees in representative types of work possess definite attitudes as to when during the work shift they are most tired. They concluded that maximal subjective fatigue is reported in the fourth and eighth hours of an 8 hour shift. Their data for the percent "most tired" of 232 manual workers between 20 and 35 years of age is graphed in Figure 1.

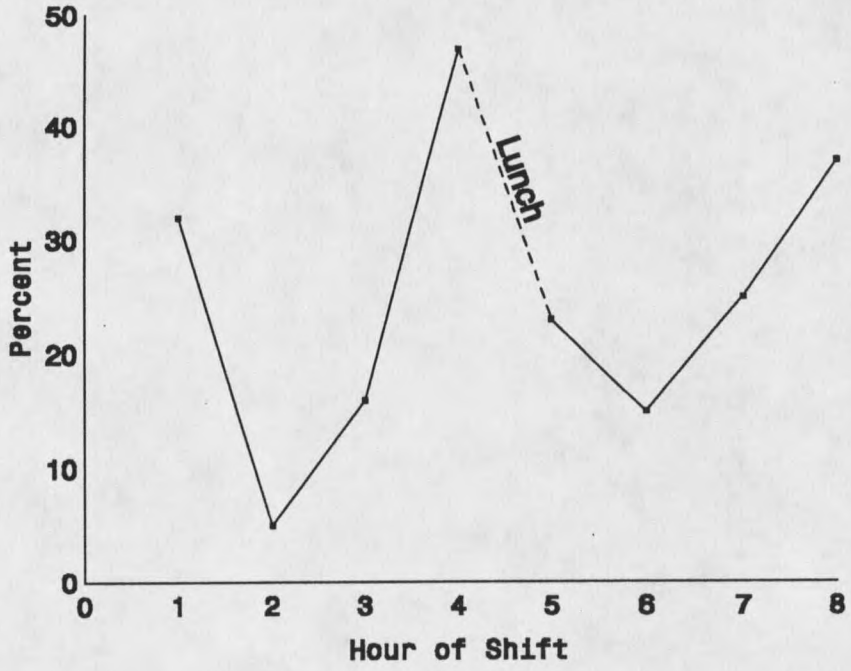


Figure 1. Percent "Most Tired" Among Manual Workers Ages 20 to 35. Source: Griffith et al. (1950)

The use of the psychophysical method in the development of permissible loads for manual handling tasks has several advantages and disadvantages as reported by Snook (1985). The advantages include: (1) Psychophysics permits the realistic simulation of industrial work. (2) Psychophysics can be used to study the very intermittent tasks that are commonly found in industry. A physiologically steady state is not required. (3) With the exception of very fast frequency tasks, psychophysical results are consistent with metabolic criteria of continuous or occasional work capacity. (4) Psychophysical results are reproducible. (5) Psychophysical results appear to be related to low-back pain.

The disadvantages include: (1) Psychophysics is a subjective method that relies upon self-report from subjects. (2) Psychophysical results from very fast frequency lifting tasks are higher than recommended metabolic criteria. (3) Psychophysics does not appear to be sensitive to the bending and twisting motions in lifting that are associated with the onset of low-back pain.

Upper Extremity Research

The wrist is frequently affected by (CTD's). There are physiological, angular and duration upper limits for the capacity of what the majority of the work force can do safely with their hands.

Upon these premises, Tanaka and McGlothlin (1993) proposed that the product of values of internal forces, repetition and angles of the hand/wrist motion must remain under certain limits. They proposed a conceptual mathematical model for epidemiological and experimental verification that is believed to contain the appropriate risk factors:

$$ELM = k * \alpha * F * \beta * R * e^{\gamma A} \qquad (3)$$

where: ELM = exposure limit for manual task
F = internal musculoskeletal force
R = repetition
A = wrist angle
$\alpha\beta\gamma$ = coefficients for each corresponding factor
k = a constant to be determined for worker protection

Equation 3 is graphically presented three-dimensionally in Figure 2 with a concavity towards the top of the Figure.

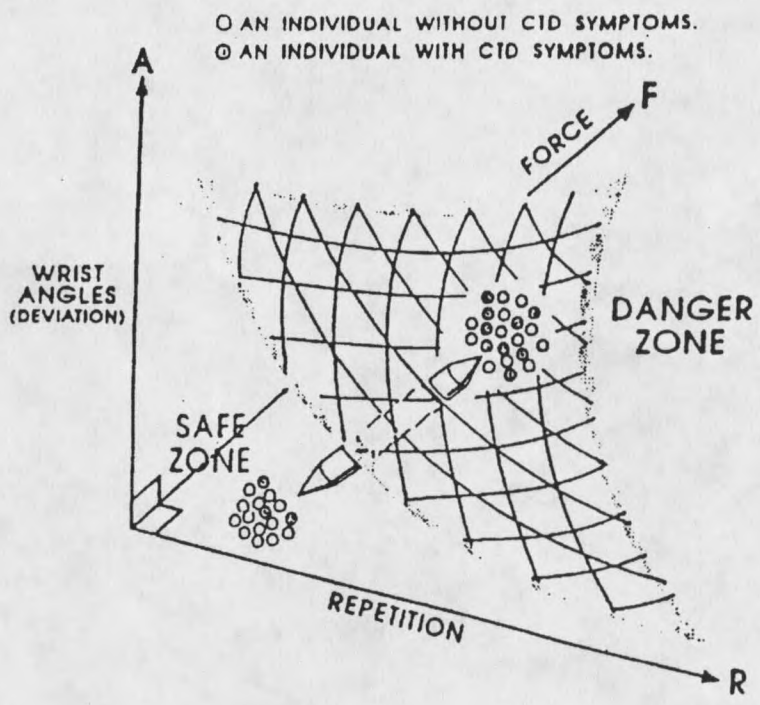


Figure 2. Graphical Representation of Equation 3. Source: Tanaka and McGlothlin (1993)

From Figure 2 it can be seen that if one factor is maximized the other two must be minimized to stay below the ELM. These maximums are uncommon but helpful in defining the curved plane.

A set of such planes is a fuzzy band with some thickness to accommodate a variety of individuals. The area below the fuzzy band are jobs which could be performed by most workers without CTD risk, and above it are jobs which would produce symptoms in a large portion of workers. Within the band, some workers may be at risk while others are not.

Individual differences may be visualized as clusters of small spheres as shown in Figure 2. Each sphere represents the data from a single worker. Dotted spheres represent individuals with CTD symptoms while individuals without symptoms are represented with blank spheres (Tanaka and McGlothlin 1993).

According to Armstrong and Chaffin (1979), LeVeau et al. (1977) compares a tendon sliding over a curved surface as being analogous to a belt wrapped around a pulley. The force exerted on the pulley is represented by the following formula:

$$F_L(\text{force/arc length}) = (F_t e^{\mu\theta})/r \qquad (4)$$

where: F_L = force on pulley
F_t = belt tension
r = radius of the pulley curvature
μ = coefficient of friction
θ = angle of pulley/belt contact

The coefficient of friction has been established to be in the range of 0.01 - 0.1 and can be neglected without greatly affecting force estimates. Thus, equation (4) can be approximated by:

$$F_L = F_t/r \qquad (5)$$

The radius of curvature can be estimated for different wrist thicknesses, and tendon tension can be estimated for given positions of given sized hands.

Krawezyk et al. (1993) studied different combinations of representative upper extremity work using established

psychophysical methods. The lowest mean overall perceived exertion was observed when the task workload was evenly distributed between the left and right upper extremity. The balanced task allowed the maximum amount of physiological recovery time, thus, accounting for the lower perceived exertion and verifying the link between RPE and physiological output.

Marley and Fernandez (1991) conducted a psychophysically determined maximum acceptable frequency (MAF) drilling task. No significant differences between replicates of the neutral wrist position were found for frequency, RPE or the physiological response variables measured. This data suggest that the psychophysical approach yields reliable results for upper extremity work.

Fernandez et al. (1993) summarized data collected to date for males and females at various wrist postures using a pistol-grip pneumatic drill in a task requiring 12 lbs. of force in Table 4. It was concluded that several factors effect MAF. Males tended to select higher MAF values than did females ($p < 0.05$). Wrist posture had a significant effect ($p < 0.05$) on MAF with flexion producing the lowest values. Each discrete increase in wrist flexion resulted in a significant decrease in MAF ($p < 0.05$). In other postures, MAF values tended to decrease with increased deviation although not significantly ($p < 0.05$).

Table 4. MAF Per Minute in Mean(STD) at Various Wrist Postures for Males and Females.

Wrist Posture	Degree Deviation	MAF males	MAF females
Neutral	0	14.83(3.02) n=15	12.10(2.70) n=39
Flexion	10	13.00(2.92) n=15	10.50(2.26) n=27
	20	11.90(2.45) n=15	9.30(1.84) n=27
	25	____	9.40(2.63) n=12
	30	10.40(2.38) n=15	____
	40	8.90(1.75) n=15	____
	50	____	8.22(3.22) n=12
Extension	20	____	11.50(3.31) n=15
	40	____	10.90(2.29) n=15
Ulnar Deviation	15	____	11.30(2.36) n=12
	20	____	12.20(3.45) n=12
	30	____	10.40(2.72) n=12
	40	____	12.90(3.95) n=12
Radial Deviation	10	____	11.70(3.19) n=12
	20	____	11.10(3.46) n=12

Source: Fernandez et al. (1993)

CHAPTER 3

OBJECTIVES AND RATIONALE

Repetitive and forceful exertions are generally thought to be responsible for a large portion of CTD, particularly if combined and/or in deviated postures (Kroemer 1989). Establishing work limits and designing tasks within these limits can reduce CTD occurrence (Tanaka and McGlothlin 1993).

Several studies have been conducted which used the psychophysical method to establish materials handling guidelines (Ljungberg et al. 1982, Mital 1983, Foreman et al. 1984, Griffin et al. 1984, Karwowski and Ayoub 1984, Legg and Myles 1985, Karwowski and Yates 1986, Mital 1986, Mital et al. 1987, Fernandez and Ayoub 1988, Fernandez et al. 1991). However, comparatively, few studies have focused on establishing psychophysically determined guidelines for upper extremity tasks. The use of psychophysical methods are justified by the fact that there are no widely accepted biomechanical or psychophysical models for determining repetitive manual work guidelines for multiple factors (Tanaka and McGlothlin 1993).

Before more research is conducted in this area, the reliability of applying the psychophysical method to tasks

which involve dynamic upper extremity work while the lower extremity remains static must be established. This study attempted to do this for a simulated drilling task.

It was hypothesized that the psychophysical method would be found to be reliable and that associations between HR and MAF and HR and RPE would be found. The specific objectives of this study are listed below:

1) To determine the reliability of applying psychophysical methods to the upper extremity when different bouts, times of day, weeks, order of testing and the interactions thereof are factors.

2) To establish the relationship between an objective criterion, in this case HR, and MAF when the psychophysical method is applied to upper extremity work.

3) To determine the relationship between RPE and HR for upper extremity work.

CHAPTER 4

METHODS AND PROCEDURES

Subjects

Subjects for this study were randomly selected from qualifying volunteers from the student body of Montana State University. Six (6) male subjects were selected. Subjects were not compensated for their time. The responses of industrial and non-industrial workers to task variables are very similar (Mital 1986). Therefore, relevant industrial experience was not a factor in subject selection.

Subjects were screened using the questionnaire in Appendix A (modified from Davis 1992) and by conducting a Phalen's test. Screening was conducted so as to exclude any individuals who had a history of cumulative trauma of the upper extremity.

A Phalen's test is conducted by positioning the wrists in complete flexion Figure 3. Maintaining this position for approximately one minute will cause numbness and tingling in normal hands. These symptoms are more intense and occur quicker when the median nerve is already somewhat compressed (Phalen 1966).

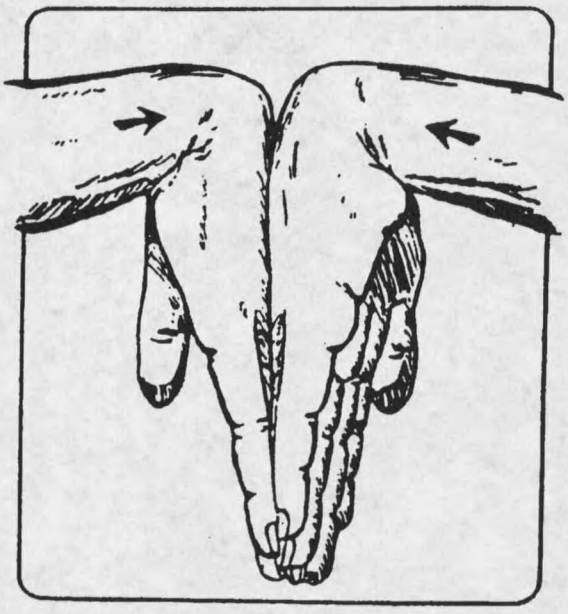


Figure 3. Phalen's Test. Source: Putz-Anderson (1988)

Only subjects who responded negatively on both the screen and the Phalen's test were accepted. All subjects were required to sign an informed consent (Appendix A).

The anthropometric and strength measures listed in Table 5 were taken and the statistics listed were calculated (Chaffin 1975). This data were tested based on the hypothesis that $\mu = \mu_0$ (Mathiowetz et al. 1985 and Pheasant 1986).

Table 5. Subject Data.

X	N	Min	Max	Range	Mean	Var.	Std. Dev.	Median	Pop. Mean	T-test Value	p Values
AGE	6										
STATURE	6										
WT	6										
ELBOW HT	6										
NTRL GRP	6										
PINCH	6										

* Statistically Significant ($p < 0.05$)

Equipment

Anthropometric measures were taken using a standard anthropometric kit. Grip strength was determined using a Jamar Grip Dynamometer. Pinch strength was assessed with a Jamar Hydraulic Pinch Gauge. Heart rate was measured with a Polar Heart Rate Monitor. Body weight was measured on a Seca scale.

An apparatus which simulates a sheet metal drilling activity was constructed, Figures 4 and 5. The apparatus was mounted on a Lido Workset to allow vertical adjustment and pitch. This apparatus and the equipment used were designed and selected in order to resemble the equipment used by Marley and Fernandez (in press).

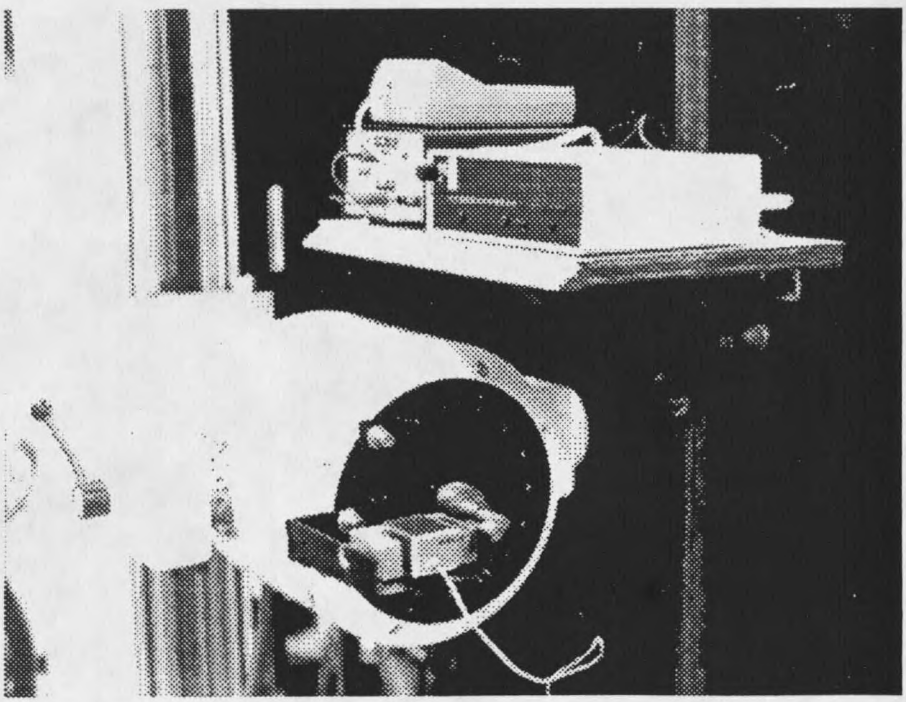


Figure 4. Simulated Work Station (Side View).

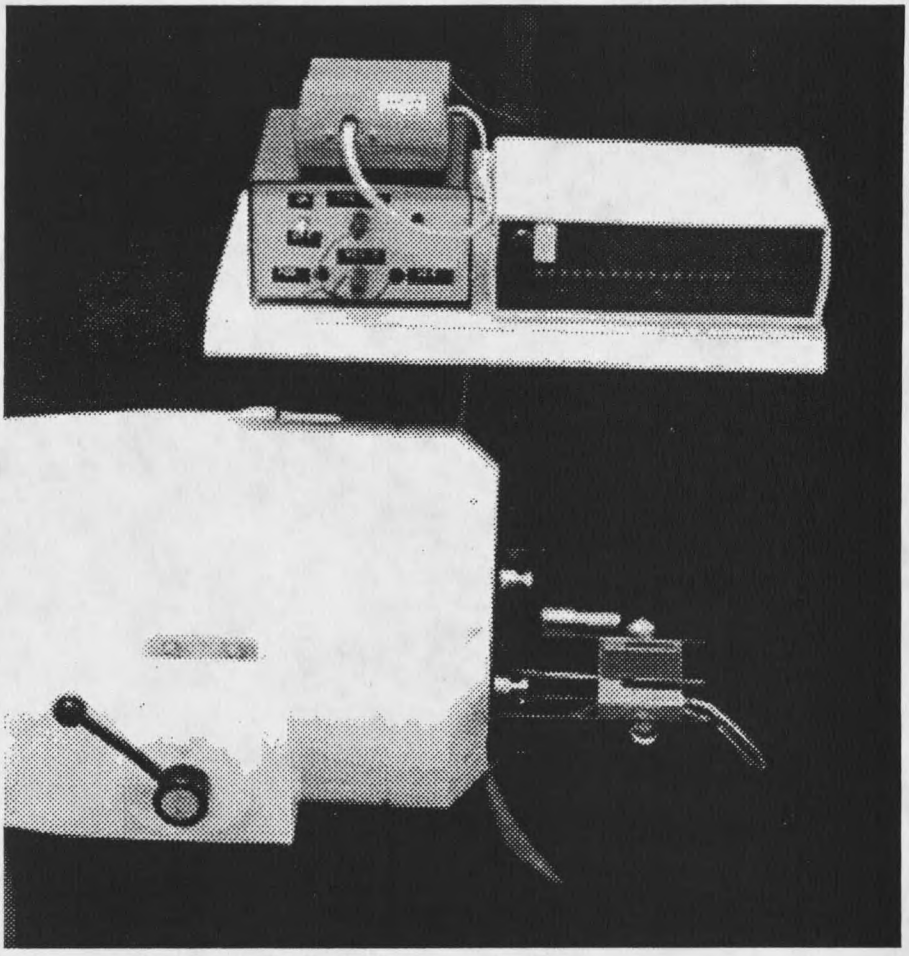


Figure 5. Simulated Work Station (Front View).

This work station utilized an Interface SM-500 load cell mounted behind a "target hole". The load cell had a range of 0 to 500 pounds and was powered by a 5 volt supply. A Skil model 2130 cordless pistol-grip hand held drill weighing 1.87 lbs. equipped with a false bit was used to apply force to the load cell through the "target hole".

Force applied to the load cell was registered on a LED bar graph which responded from left to right, using amber, green and red lamps respectively, with increased force.

Output gain was adjusted so that the required 12 pounds of force (± 0.5 pounds) was indicted by the green lamps. When the force applied equaled at least 11.5 pounds (green lamp area) an event timer was triggered which delayed for 1 second before lighting a separate cluster of 4 red "release" lamps and emitting an auditory cue.

Task frequency was controlled by a subject adjusted metronome via a 10-turn potentiometer. The potentiometer had no markings by which the subject could gauge the frequency selected. Frequency was increased by turning the potentiometer clockwise. An auditory cue at a different pitch than the "release" auditory cue was emitted at the frequency set by the subject. An attached counter recorded the seconds between frequency auditory cues, and this value was manually converted to frequency/minute. An Armitron hand-held stopwatch was used to time bout lengths.

Differences exist between the apparatus and equipment used by Marley and Fernandez (in press) and that used in this study. The vertical adjustment for the "target hole"/load cell configuration in this study was adjustable in smaller increments than the vertical adjustment in the study conducted by Marley and Fernandez (in press). The degrees of freedom in adjustment of the apparatus in this study were 2 whereas the one used by Marley and Fernandez (in press) utilized 3. Also, the weight of the drill used was 1.13 lbs. less than the one used by Marley and Fernandez (in press).

Procedures

Subjects performed a task similar to the one performed by Marley and Fernandez (in press). All tasks and anthropometric data were performed and measured while standing using the subjects' dominant side. The simulated drilling task was performed in the neutral position defined as the arm adducted, 90^0 elbow flexion, forearm parallel to the floor and mid-pronated and 0^0 flexion, extension, radial deviation and ulnar deviation (Mathiowetz et al. 1984) (Figures 6 and 7).

Anthropometric and Strength Measures

Subject stature and standing elbow height were measured as the vertical distance from the floor to the vertex and to the radiale respectively (Pheasant 1986).

Grip strength was recorded with the arm in the neutral position. Palmer (three-jaw chuck) pinch strength was recorded by the having the subject grasp the pinch gauge between the tips of the thumb and index and long fingers with the upper arm in the neutral position (Mathiowetz et al. 1984).

For each strength measure the average of three maximum voluntary contractions, defined as gradually increasing exertion until maximum effort is reached and maintaining this maximum for two seconds, was recorded (Marley and Fernandez in press).

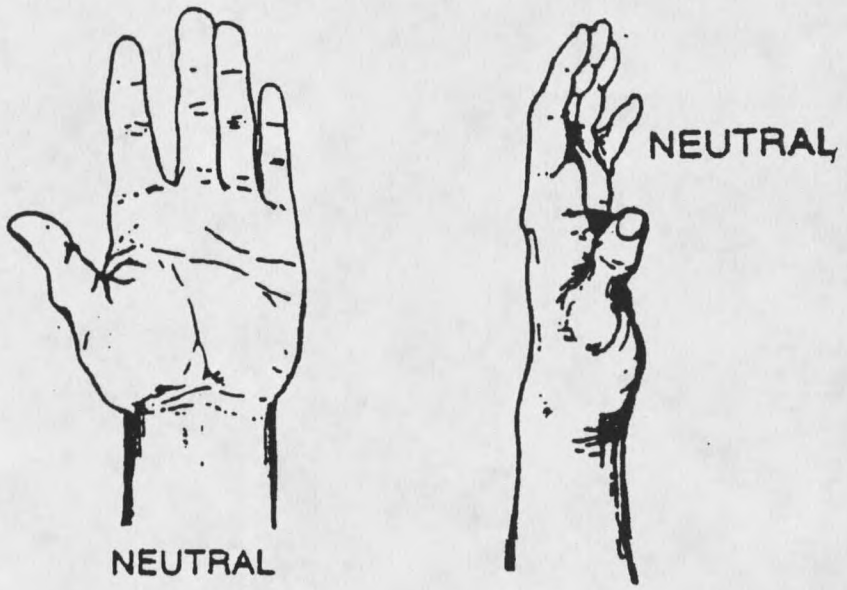


Figure 6. Neutral Positions of the Wrist. Source: Put-Anderson (1988)

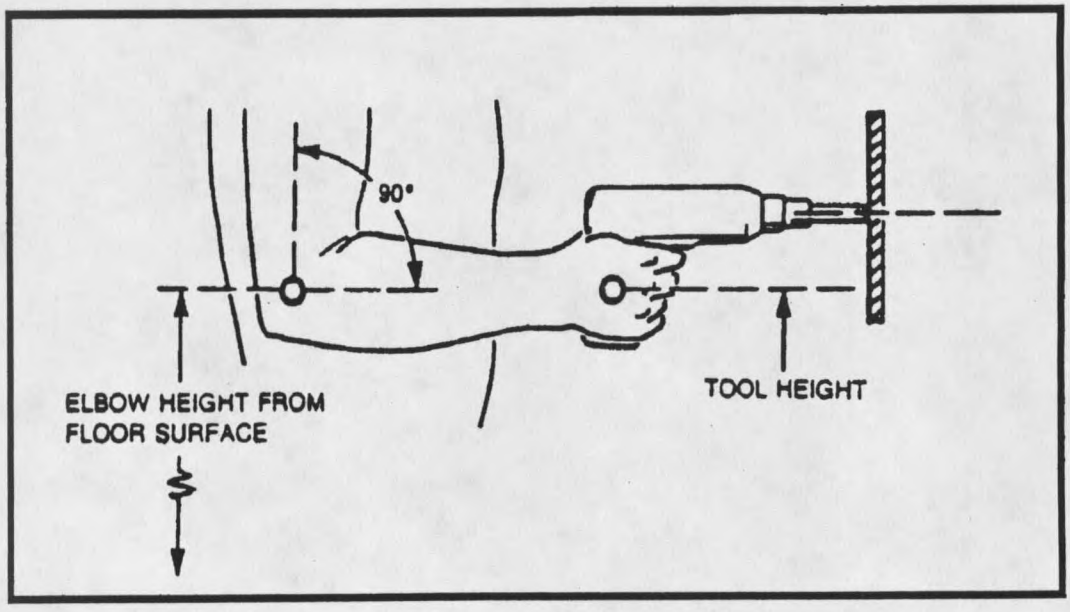


Figure 7. Simulated Drilling Posture. Source: Putz-Anderson (1988)

Simulated Drilling Task

The subjects were required to stand facing the work station holding the drill with the false bit in the neutral position at no more than a 6-inch perpendicular distance from the vertically mounted "target hole". This was referred to as the "starting position" (Marley and Fernandez in press). The "target hole" was vertically adjusted to the same height as the subjects standing elbow height.

In a certain sheet metal drilling task, it was determined that 12 pounds of force must be applied for at least 1 second in order to complete the drill (Marley and Fernandez in press). These parameters were utilized in this study.

A drilling cycle began with the subject holding the drill in the starting position. Upon receiving an auditory cue from the LED, the subject inserted the false bit into the "target hole" putting pressure on the load cell. Once the required force was achieved, 12 lbs., as indicted by the green lamps for the required period of time, 1 second, as indicted by the 4 red lamp cluster and an auditory cue, the false bit was removed and the subject returned to the starting position, thus completing 1 cycle.

Each subject was required to perform 16, 30-minute drilling bouts. Four bouts were performed each testing session. The required four sessions were divided between 2 weeks and AM/PM periods.

An AM and PM session was performed in each of the 2 weeks with at least 1 and a maximum of 3 days between sessions in any given week. There was a 7 to 10-day interval between Week 1 and Week 2.

Subjects were randomly divided into 2 groups. Group 1 performed their first session in Week 1 in the AM and their second session in the PM. This order was reversed for Group 1's second Week. Group 2 performed their first session in Week 1 in the PM and their second session in the AM. This order was also reversed for Group 2's second Week.

Familiarization Period

During this period, subjects were screened and those who were found to be eligible to participate had their anthropometric measures taken. These subjects were also introduced to the equipment and procedures and performed a 1-hour (2 bout) mock running of the experiment.

The goals of the familiarization period were: (1) to familiarize the subjects with the use of the equipment, (2) to familiarize the subjects with the psychophysical methodology which will be used in determining (MAF), (3) to tone the involved muscle groups and (4) to allow the experimenter and subject to get acquainted so as to enhance cooperation (Fernandez 1986).

Psychophysical Frequency Determination

During each bout a psychophysically adjusted drilling frequency was determined by the method of adjustment. The initial frequency was randomly set relatively high or low.

Subjects were allowed to adjust the drilling frequency using the potentiometer. Subjects were instructed to adjust the frequency based on what they felt they could maintain for an 8 hour workday (Appendix A), (Snook and Irvine 1967, Snook and Irvine 1968, Snook et al 1970, Snook and Ciriello 1974, Snook 1978, Ciriello and Snook 1983). These instructions were read and explained to each subject at the beginning of their first testing session, and subjects were briefly reminded of them at the beginning of each remaining testing session.

The adjustment period lasted 20 minutes. The frequency set at the end of the 20 minutes was considered the (MAF). This frequency was maintained for an additional 5 minutes so as to allow the subject to reach a physiological steady state (Marley and Fernandez in press).

At the end of this 5-minute period the subject's HR and the MAF were recorded in the data collection form, Figure 26, shown in Appendix A. Also, a whole body (RPE) was taken (Corlett and Bishop 1976, Genaidy et al 1989). The Borg 15 point scale, Figure 25 in Appendix A, was used to rate the subjects' perceived exertion (Borg 1970). After these measures were taken, a 5-minute rest period was allowed, thus completing one 30-minute bout.

There are two Borg scales, an 11 point and a 15 point. The 15-point scale was selected for use in this study because it is the best one for most simple applied studies of perceived exertion. Whereas, the 11-point category scale is more suitable for rating breathing difficulties, aches and pains (Borg 1982).

At no time during the duration of this study were subjects told the values of their MAF's or of any other subjects' response variables. Also, during each individual bout, subjects were not told the time remaining in their adjustment or steady-state periods.

Experimental Design

This experiment was conducted and analyzed as a mixed model. The hypotheses tested were that the mean values of the response variables were not significantly different at the $\alpha = .05$ due to Group, Week, Time, Bout or the interactions thereof. The Systat PC-based statistical package in the Montana State University Human Factors Laboratory was used to analyze the data.

This experiment could not be analyzed as a crossover or sequential design because all the factors did not occur at two levels and because it could not be broken down into sets of Latin squares (Collier and Hummel 1977, Montgomery 1984).

The experiment consisted of five independent and three dependent variables (Table 6). The Subject factor was nested

within the Group factor. Group, Week and Time had two levels, and Subject and Bout had three and four levels respectively.

Table 6. Variable List.

Class	Variable
Independent	Group Week Time Bout Subject
Dependent	Rating of Perceived Exertion (RPE) Heart Rate (HR) Maximum Acceptable Frequency (MAF)
Controlled	Population (college students) Gender (male) Force Requirements (12 pounds) Duration (30 minute bouts) Weight of Tool (1.87 lbs.) Vibration and Torque (none) Arm Posture (neutral)

Subjects were assigned to groups based on the first and third columns of random numbers shown in Table 16 in Appendix A generated by Lotus for Windows. Subject numbers which corresponded to odd random numbers were put in Group 1 and all other subjects were put in Group 2. Numbers were assigned to subjects consecutively based on the order in which they completed their familiarization period. No more than 3 subjects were assigned to any one Group.

Legg and Myles (1985) and Sharp and Legg (1988) showed that alternating the starting weight of lift when using the psychophysical method of adjustment was not a significant factor. Therefore, the starting frequency in this experiment was not considered a factor. The drill was not powered, therefore, the effects of torque and/or vibration were also not considered factors.

The starting frequency was randomly set high or low, based on the first and second, fourth and fifth and sixth and seventh columns of random numbers shown in Table 16 in Appendix A generated by Lotus for Windows. Cell numbers corresponding to odd random numbers started at high frequencies and those corresponding to even random numbers were started at low frequencies.

Cells were assigned numbers 1 through 96 starting with Subject 1, Group 1, Week 1, Time 1 and Bout 1 continuing consecutively to Subject 3, Group 2, Week 2, Time 2 and Bout 4. A low frequency was defined as 3 or less per minute. A high frequency was defined as 15 or more per minute.

The task was repeated sixteen times per subject (see Simulated Drilling Task section) with the varying times at which the task was performed being the factors of interest. Table 7 displays the design layout for all three dependent variables.

The use of six subjects was determined based on the number of degrees of freedom remaining for the error term after constructing an anticipated ANOVA (Table 8). The fourth and greater interactions were used as error due to the difficulty in explanation if they would have been found to be significant (Hicks 1982).

Table 7. Experimental Design Layout for RPE, HR and MAF.

		Week															
		1								2							
		Time								Time							
		am				pm				am				pm			
		Bout				Bout				Bout				Bout			
Group	Subject	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	1																
	2																
	3																
2	4																
	5																
	6																

Table 8. Anticipated ANOVA.

Source	df	i	j	k	l	m	n	EMS
G_i	1	0	3	2	2	4	1	$\sigma_e^2 + 16\sigma_{GS}^2 + 48\phi_G$
$S_{j(i)}$	2	1	1	2	2	4	1	$\sigma_e^2 + 16\sigma_S^2$
W_k	1	2	3	0	2	4	1	$\sigma_e^2 + 48\phi_W$
T_l	1	2	3	2	0	4	1	$\sigma_e^2 + 48\phi_T$
B_m	3	2	3	2	2	0	1	$\sigma_e^2 + 24\phi_B$
$GS_{ij(i)}$	2	1	1	2	2	4	1	$\sigma_e^2 + 16\sigma_{GS}^2$
GW_{ik}	1	0	3	0	2	4	1	$\sigma_e^2 + 24\phi_{GW}$
GT_{il}	1	0	3	2	0	4	1	$\sigma_e^2 + 24\phi_{GT}$
GB_{im}	3	0	3	2	2	0	1	$\sigma_e^2 + 12\phi_{GB}$
WT_{kl}	1	2	3	0	0	4	1	$\sigma_e^2 + 24\phi_{WT}$
WB_{km}	3	2	3	0	2	0	1	$\sigma_e^2 + 12\phi_{WB}$
TB_{lm}	3	2	3	2	0	0	1	$\sigma_e^2 + 12\phi_{TB}$
GWT_{ikl}	1	0	3	0	0	4	1	$\sigma_e^2 + 12\phi_{GWT}$
GWB_{ikm}	3	0	3	0	2	0	1	$\sigma_e^2 + 6\phi_{GWB}$
GTB_{ilm}	3	0	3	2	0	0	1	$\sigma_e^2 + 6\phi_{GTB}$
WTB_{klm}	3	2	3	0	0	0	1	$\sigma_e^2 + 6\phi_{WTB}$
$\varepsilon_{n(ijklm)}$	63	1	1	1	1	1	1	σ_e^2

CHAPTER 5

RESULTS AND DISCUSSION

Subjects

Six subjects were recruited from the student body at Montana State University. All subjects were in the College of Engineering. Measures, X, and their statistics shown in Table 9 were taken and calculated. The values of these measures for each subject are shown in Table 17 in Appendix B.

Table 9. Subject Descriptive Statistics.

X	N	Min	Max	Range	Mean	Var.	Std. Dev.	Median	Pop. Mean	T-test Value	p Values
AGE	6	22.0	29.00	7.00	24.17	6.57	2.56	23.00			
STATURE	6	176.0	189.00	13.00	180.58	22.24	4.72	178.75	175.50	2.64	0.046 *
WT	6	73.0	110.00	37.00	83.17	189.37	13.76	78.50	76.36	1.21	0.280
ELBOW HT	6	113.0	118.00	5.00	115.08	3.34	1.83	114.50	110.50	6.14	0.002 *
NTRL GRP	6	45.0	70.67	25.67	55.23	85.35	9.24	54.85	55.00	.06	0.954
PINCH	6	9.7	12.83	3.13	11.47	1.45	1.20	11.69	12.09	-1.26	0.263

* Statistically Significant ($p < 0.05$)

Population means of the subject data values were tested based on the hypothesis that $\mu_x = \mu_0$ (Appendix B). Sample statistics collected by Mathiowetz et al. (1985) and Pheasant (1986) for the U.S. male population were used as point estimates for μ_0.

Population means for stature and elbow height, were found to significantly differ from μ_0, $\alpha = 0.05$. Sample data for these two measures were highly correlated (Appendix B).

Population means for the measures which might affect the dependent variable values, weight, grip, and pinch strengths, were not significantly different from μ_0; and, their sample data were not highly correlated to stature or elbow height (Appendix B). Therefore, it can be concluded weight, grip, and pinch strengths are representative of the U.S. male population.

Population means for these five measures for Group 1 and Group 2 were compared to each other using "t" tests concerning the difference between two means based on the hypothesis that $\mu_1 = \mu_2$ (Appendix B). These tests showed no significant difference between Groups 1 and 2 for any of the measures taken. Therefore, it can be concluded that both Groups were statistically equal, and any differences that may be found between Groups for the dependent variables cannot be attributed to differences in the values of the independent measures taken.

Analysis

An ANOVA was performed using MAF, RPE and HR as the dependent variables. All factors, interactions and post-hoc tests were evaluated for significance using $\alpha = 0.05$ and/or $p < 0.05$.

The Subject*Group interaction was included in each ANOVA model to determine the correct error term for Group which had the random variable Subject nested within. Terms in the model which included the Subject factor were not evaluated since Subject is a nuisance factor meaning it is assumed that significant differences will naturally occur and are random.

The raw data collected are shown in Table 18 in Appendix C. The means and standard deviations of each dependent variable for the different independent variable levels are displayed in Tables 10, 11 and 12.

Table 10. Means and (Standard Deviations) for MAF (n/cell = 3).

		Week			
		1		2	
		Time		Time	
Group	Bout	1	2	1	2
1	1	12.103(3.694)	12.463(3.502)	13.420(3.494)	13.817(4.692)
	2	11.983(3.933)	12.880(3.080)	13.950(4.336)	13.973(3.061)
	3	13.317(2.726)	13.247(3.172)	13.277(3.433)	13.350(4.201)
	4	12.183(3.822)	12.990(3.421)	13.563(3.482)	14.123(4.252)
2	1	10.617(2.716)	10.023(2.482)	11.390(1.731)	12.277(2.039)
	2	11.543(2.352)	10.180(1.225)	11.057(1.973)	13.207(3.047)
	3	11.407(2.550)	11.723(1.813)	13.623(2.915)	14.890(3.338)
	4	11.360(2.120)	11.383(1.494)	12.663(2.516)	13.250(0.936)

Levels of factors which were distinguished by numbers will be referred to by their factor title and their corresponding numbers. The Time factor's levels are defined as follows: AM = Time 1, PM = Time 2.

Table 11. Means and (Standard Deviations) for RPE (n/cell = 3).

		Week 1		Week 2	
		Time		Time	
Group	Bout	1	2	1	2
1	1	12.000(1.000)	11.333(1.155)	12.333(0.577)	11.667(1.528)
	2	12.000(1.000)	11.667(2.082)	13.000(1.000)	12.333(2.082)
	3	12.667(1.528)	12.000(1.732)	12.667(0.577)	11.667(1.528)
	4	12.333(1.155)	11.667(1.528)	12.667(0.577)	12.333(2.082)
2	1	13.000(1.732)	13.000(1.000)	11.667(0.577)	13.000(1.732)
	2	13.333(1.528)	13.667(1.528)	11.667(0.577)	14.000(1.000)
	3	13.000(1.000)	14.000(1.000)	12.000(1.000)	13.667(1.155)
	4	13.333(1.528)	13.667(1.155)	12.333(0.577)	13.667(1.155)

Table 12. Means and (Standard Deviations) for HR (n/cell = 3).

		Week 1		Week 2	
		Time		Time	
Group	Bout	1	2	1	2
1	1	79.000(3.606)	80.333(7.638)	80.667(3.786)	76.333(11.015)
	2	79.667(1.528)	82.333(2.517)	79.333(2.082)	73.667(4.726)
	3	78.667(0.577)	79.667(1.528)	76.000(6.083)	72.000(6.000)
	4	78.667(2.082)	83.333(6.110)	83.000(3.000)	76.667(5.132)
2	1	87.667(6.028)	109.000(1.732)	98.000(9.165)	93.667(4.041)
	2	93.333(3.215)	107.333(5.033)	93.333(9.504)	85.000(2.646)
	3	92.333(5.508)	98.667(6.028)	96.000(6.928)	84.667(4.619)
	4	90.667(6.110)	101.333(3.786)	94.000(9.000)	83.000(3.606)

Psychophysical Reliability

Residual analysis showed the errors in the MAF data to be normally distributed (Figures 8 and 9). The MAF ANOVA, Table 13, revealed that Week and Bout were significant effects.

The mean MAF for Week 2 was significantly greater than the mean MAF for Week 1, 13.239 and 11.838, respectively. Weeks 1 and 2 were differentiated by a 7 to 10-day period.

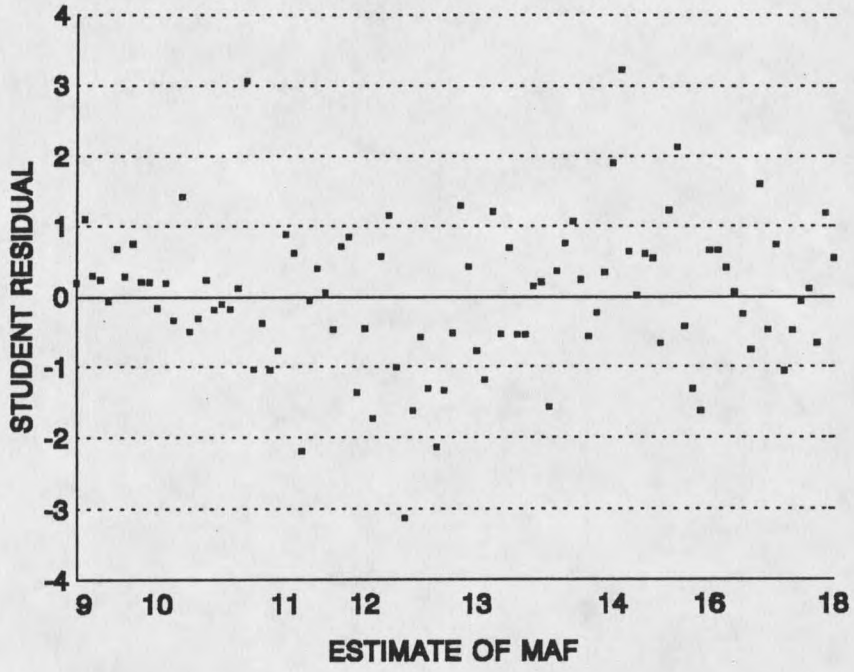


Figure 8. Residual Plot for MAF.

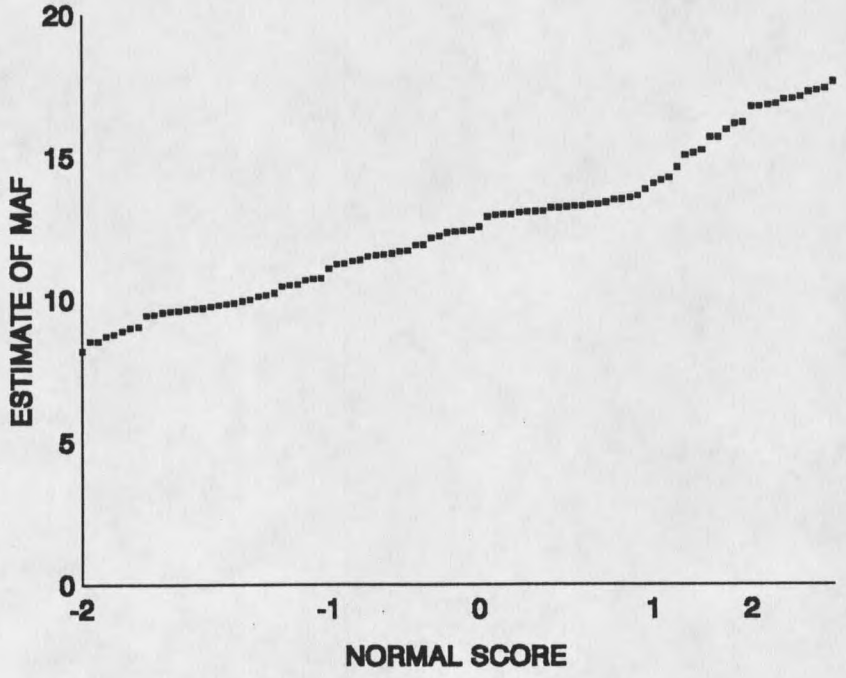


Figure 9. Normal Score Plot for MAF.

Table 13. MAF ANOVA.

Model Variables

S = Subject
G = Group
W = Week
T = Time
B = Bout
MAF = Maximum Acceptable Frequency

Categorical Variables S G W T B

Model $MAF = CONSTANT + G_i + S_{j(i)} + GS_{ij(i)} + W_k + T_l + B_m + GW_{ik} + GT_{il} + GB_{im} + WT_{kl} + WB_{km} + TB_{lm} + GWT_{ikl} + GWB_{ikm} + GTB_{ilm} + WTB_{klm} + \varepsilon_{n(ijklm)}$

Levels Encountered

S = 3
G = 2
W = 2
T = 2
B = 4

$R^2 = .871$

Analysis of Variance

Source	Sum-of-Squares	DF	Mean-Square	F-Ratio	P	
G_i	37.675	1	37.675	0.207	0.694	
$S_{j(i)}$	146.062	2	73.031	48.199	0.000	
$GS_{ij(i)}$	363.674	2	181.837	120.010	0.000	
W_k	47.152	1	47.152	31.120	0.000	*
T_l	3.745	1	3.745	2.471	0.121	
B_m	15.719	3	5.240	3.458	0.022	*
GW_{ik}	3.168	1	3.168	2.091	0.153	
GT_{il}	0.005	1	0.005	0.003	0.955	
GB_{im}	8.262	3	2.754	1.818	0.153	
WT_{kl}	2.905	1	2.905	1.917	0.171	
WB_{km}	0.015	3	0.005	0.003	1.000	
TB_{lm}	0.170	3	0.057	0.037	0.990	
GWT_{ikl}	5.199	1	5.199	3.431	0.069	
GWB_{ikm}	7.756	3	2.585	1.706	0.175	
GTB_{ilm}	1.233	3	0.411	0.271	0.846	
WTB_{klm}	1.057	3	0.352	0.233	0.873	
$\varepsilon_{n(ijklm)}$	95.457	63	1.515			

* Significant Variables that were Considered

The significant difference between them may be attributed to a learning curve. Also, the fact that Week 2 was the week before Spring break and coincided with midterm tests may have influenced the subjects' selection.

The relative difference between Weeks was only 11.834% which equals an absolute difference of 1.4 drills/minute (Appendix D). Although this factor was found to be

significant, it is not believed that this small amount of deviation is meaningful in terms of work design.

Using data compiled by Fernandez et al. (1993), a 95% confidence interval was constructed for MAF. The variances were pooled and a weighted mean used (Appendix D).

A Tukey test performed on the four levels of Bout indicated that Bouts 1 and 3 significantly differed from each other with Bout 3 being greater, 12.347 and 13.104 respectively (Appendix D).

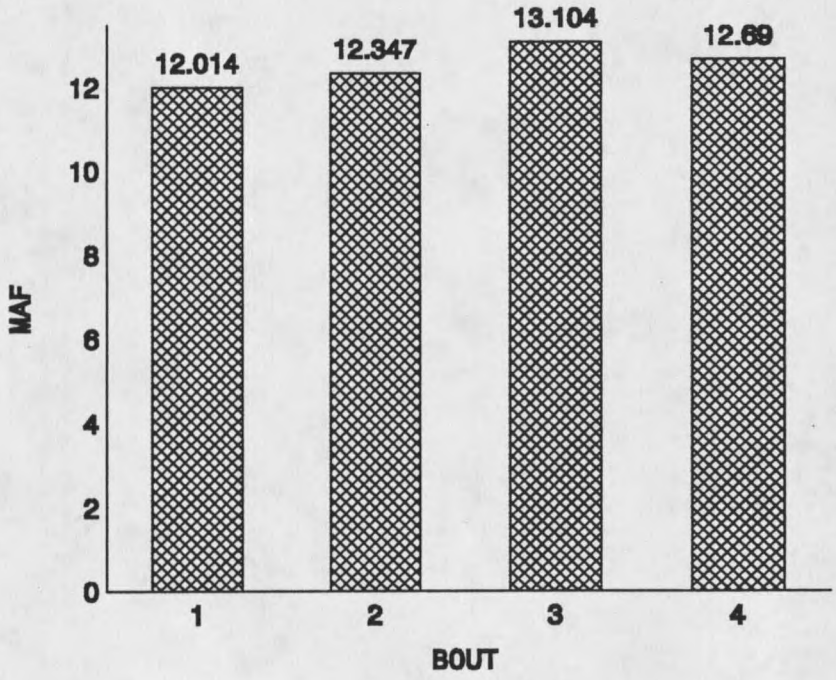


Figure 10. Bout by MAF.

The means for Bout are graphically depicted in Figure 10. The graph shows that for the first 1½-hours of each testing session, subjects' perception of the workload they could

maintain for an eight-hour period increased. However, the last ½-hour of each testing session showed a decline in MAF though not significant. Since Bouts 1 and 4 are not significantly different it can be concluded that one ½-hour bout can reliably predict the MAF that can be maintained for 2 hours.

Legg and Myles 1985 found no significant difference, $p < 0.01$, between maximum acceptable loads (MAL) selected by soldiers on five consecutive days. This study found no significant difference, $p < 0.01$, between testing days for work loads selected for the upper extremity (Appendix D). This shows that there are similarities between the reliability of the selection of work limits for lower and upper extremity tasks between different population samples.

The overall mean MAF value found in this study was not significantly different from the mean MAF for the neutral position in the data Fernandez et al. (1993) compiled (Appendix D). However, the mean MAF for Week 1 was significantly less than this complied data while the mean MAF for Week 2 was not significantly different (Appendix D and Figure 11).

The MAF means found in this study which were used for comparison were lower than the MAF value found by Fernandez et al. (1993). This difference may be due to differing laboratory conditions and the mechanical properties of the drills used.

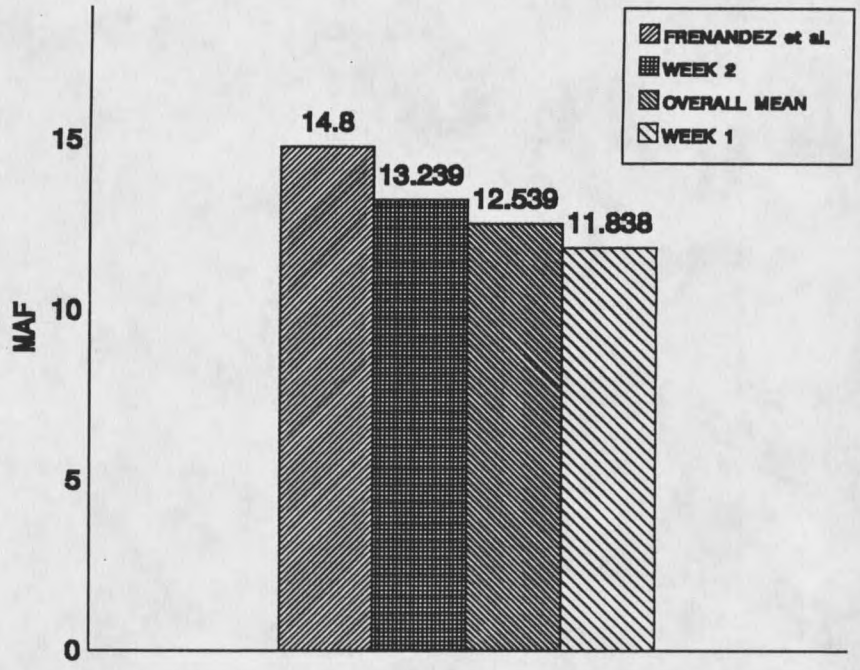


Figure 11. Mean MAF Comparisons to Published Data.

HR/MAF Relationship

From observing the Pearson Correlation Matrix for HR and MAF in Appendix E and Figure 12 one can see that HR and MAF are not highly correlated overall.

Due to individual subject differences, the correlation between HR and MAF was calculated individually for each subject. These calculations revealed that half the subjects had HR correlations of .65 or greater with MAF. However, these correlations were negative (Appendix E). Thus, as these subjects perceived a greater physiological demand they selected lower MAF's.

Because of intra-subject variation, the correlation between HR and MAF was calculated for each subject each

testing period. These calculations showed that for the twenty-four total testing periods, four had HR/MAF correlations of .65 or greater with three of these being negative (Appendix E).

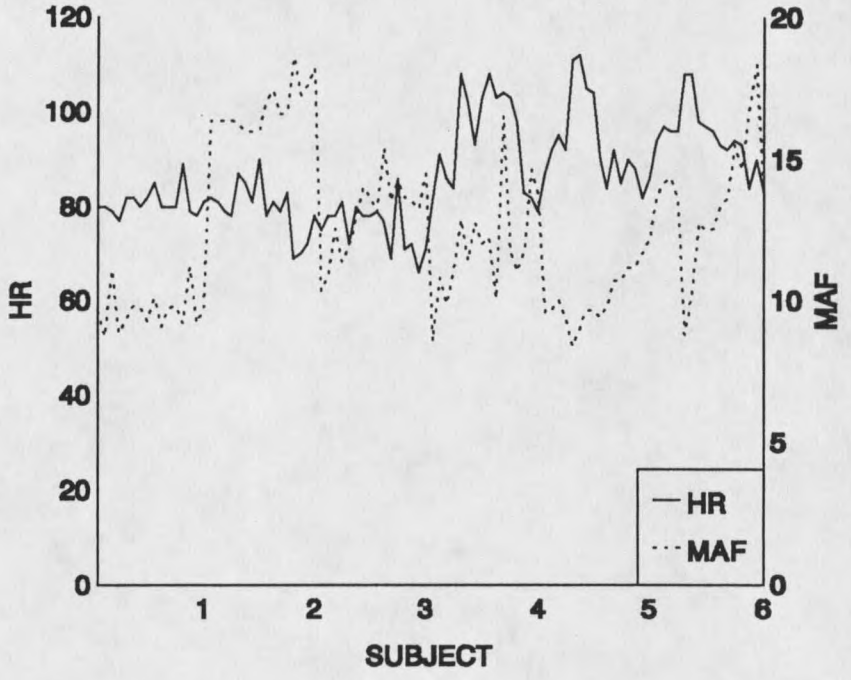


Figure 12. Subject HR/MAF Comparison.

Based on these results, one could conclude that MAF's determined by the psychophysical method of adjustment are not associated with HR for upper extremity work. However, several factors other than MAF which can affect HR were not controlled in this study such as digestion and stress.

Therefore, this study was inconclusive in determining the association between MAF's determined by the psychophysical method of adjustment when applied to upper extremity work and

HR. However, the data suggest that some subjects were able to perceive an elevated HR and thus a greater overall physiological demand and adjust their workload accordingly.

HR Analysis Residual analysis showed the errors in the HR data to be normally distributed (Figures 13 and 14). The HR ANOVA, Table 14, showed the Group, Week, Week*Time and Group*Week*Time effects to significantly affect HR.

The mean HR value for Group 2 was significantly greater than Group 1, 94.250 and 78.708 respectively. Group 2 selected a lower mean MAF than Group 1, 11.912 and 13.165 respectively. Thus, as Group 2 perceived a greater physiological demand they selected a lower MAF.

Since no significant subject differences existed between Groups, the only differentiation between Groups was the ordering of AM and PM testing periods (see Methods and Procedures). Therefore, it can be concluded that the order of testing significantly affected HR values.

The mean HR value for Week 1 was significantly greater than Week 2, 88.875 and 84.043, respectively. The differentiation between Weeks was a 7 to 10-day period. By comparing mean HR and MAF values for Weeks 1 and 2, 11.838 and 13.239 respectively, further evidence of the perception of an overall physiological demand and the adjustment of the workload accordingly can be found.

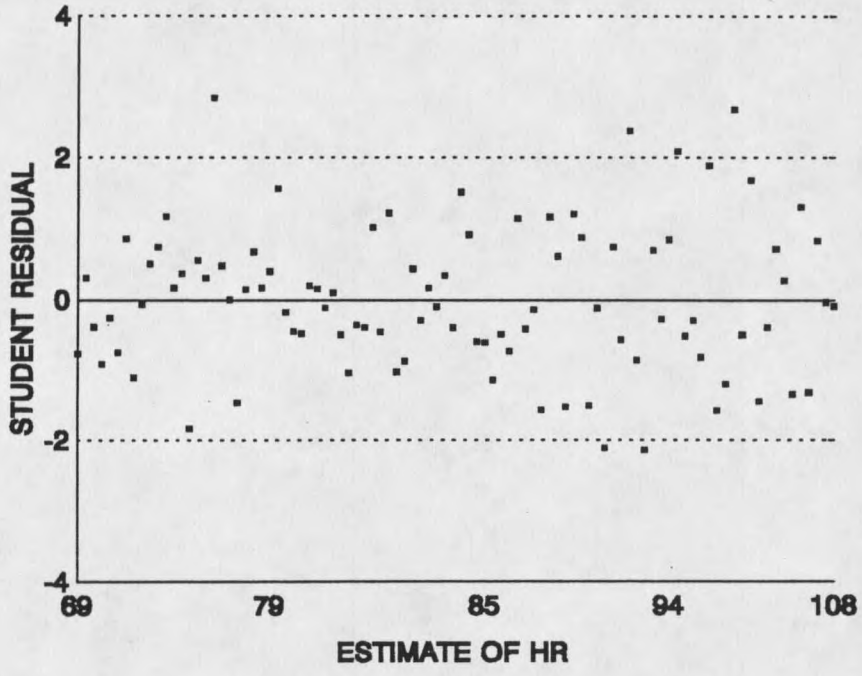


Figure 13. Residual Plot for HR.

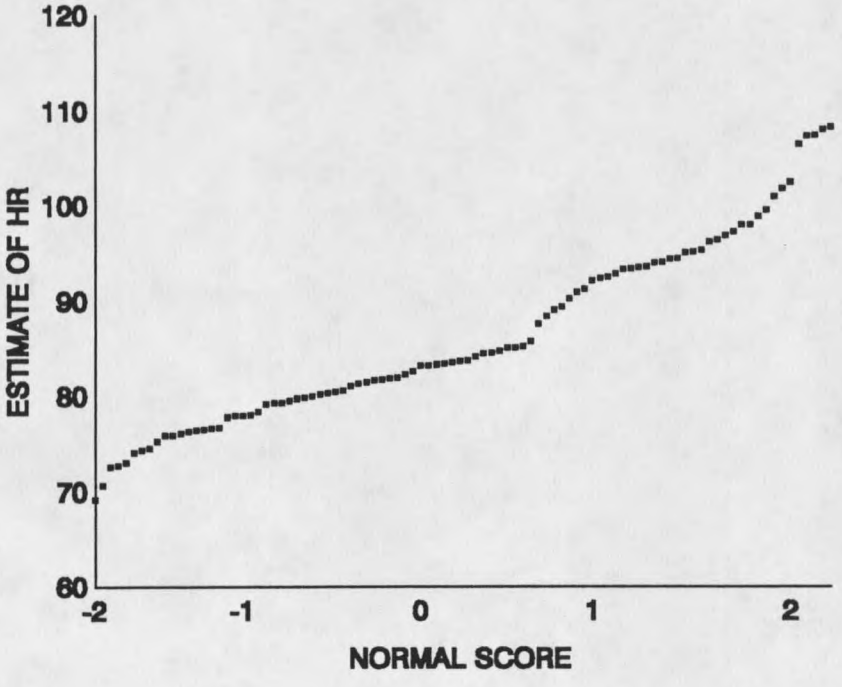


Figure 14. Probability Plot for HR.

Table 14. HR ANOVA.

Model Variables

S = Subject
G = Group
W = Week
T = Time
B = Bout
HR = Heart Rate

Categorical Variables S G W T B

Model $HR = CONSTANT + G_i + S_{j(i)} + GS_{ij(i)} + W_k + T_l + B_m + GW_{ik} + GT_{il} + GB_{im} + WT_{kl} + WB_{km} + TB_{lm} + GWT_{ikl} + GWB_{ikm} + GTB_{ilm} + WTB_{klm} + \varepsilon_{n(ijklm)}$

Levels Encountered

S = 3
G = 2
W = 2
T = 2
B = 4

$R^2 = .844$

Analysis of Variance

Source	Sum-of-Squares	DF	Mean-Square	F-Ratio	P	
G_i	5797.042	1	5797.042	67.645	0.014	*
$S_{j(i)}$	81.021	2	40.510	1.533	0.224	
$GS_{ij(i)}$	171.396	2	85.698	3.244	0.046	
W_k	551.042	1	551.042	20.858	0.000	*
T_l	4.167	1	4.167	0.158	0.693	
B_m	135.792	3	45.264	1.713	0.173	
GW_{ik}	77.042	1	77.042	2.916	0.093	
GT_{il}	73.500	1	73.500	2.782	0.100	
GB_{im}	123.792	3	41.264	1.562	0.207	
WT_{kl}	1290.667	1	1290.667	48.853	0.000	*
WB_{km}	110.125	3	36.708	1.389	0.254	
TB_{lm}	97.500	3	32.500	1.230	0.306	
GWT_{ikl}	308.167	1	308.167	11.664	0.001	*
GWB_{ikm}	52.458	3	17.486	0.662	0.579	
GTB_{ilm}	106.833	3	35.611	1.348	0.267	
WTB_{klm}	1.057	3	0.352	0.233	0.873	
$\varepsilon_{n(ijklm)}$	1664.417	63	26.419			

* Significant Variables that were Considered

A Tukey test was performed on the Week*Time interaction which indicated the factor level combinations shown in Appendix F to be significant effects (Figures 15 and 16). Week 1, Time 2 resulted in significantly greater mean HR values than all other combinations of these factors, and Week 2, Time 2 resulted in significantly lesser mean HR values than all other combinations of these factors (Appendix F).

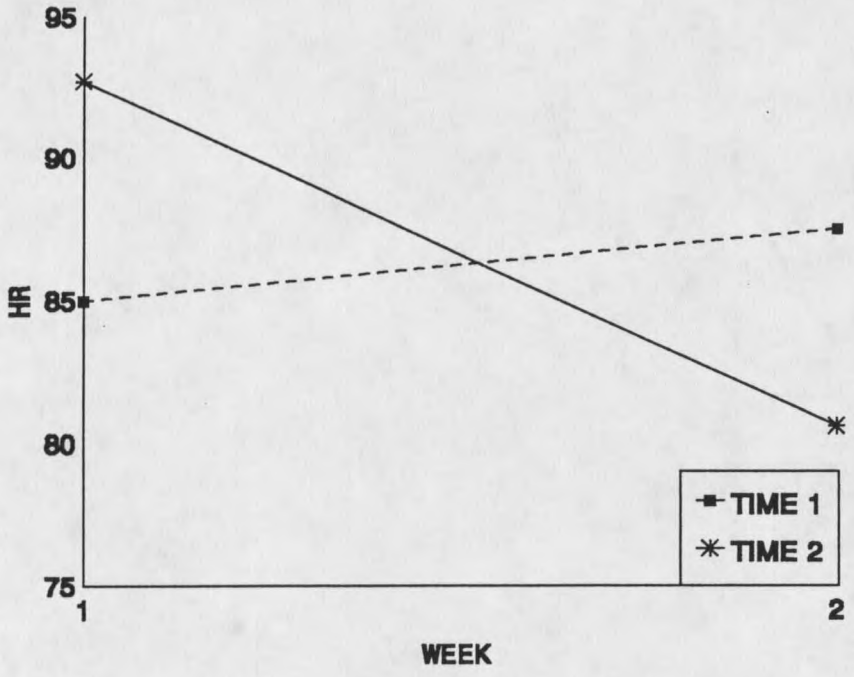


Figure 15. Week*Time Interaction for HR.

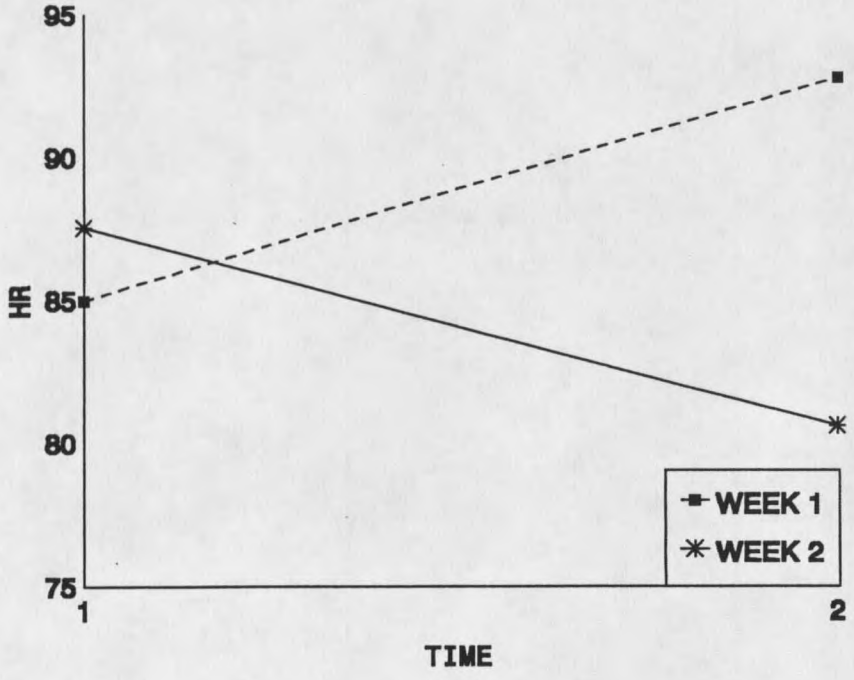


Figure 16. Time*Week Interaction for HR.

Other than these two combinations, no consistency was found for this interaction. Therefore, it can be concluded that the Week*Time interaction significantly affected HR values but in an conclusive manner. However, the lowest HR value corresponded to the highest MAF value for this interaction, 80 and 13.611 respectively, showing that as overall physiological demand decreases, subjects adjust their workload upwardly.

A Tukey test was also performed on the Group*Week*Time interaction and showed the factor level combinations in Appendix F and Figure 17 to be significant.

All combinations of Group 1 with Week and Time were significantly less than all combinations of Group 2 with Week

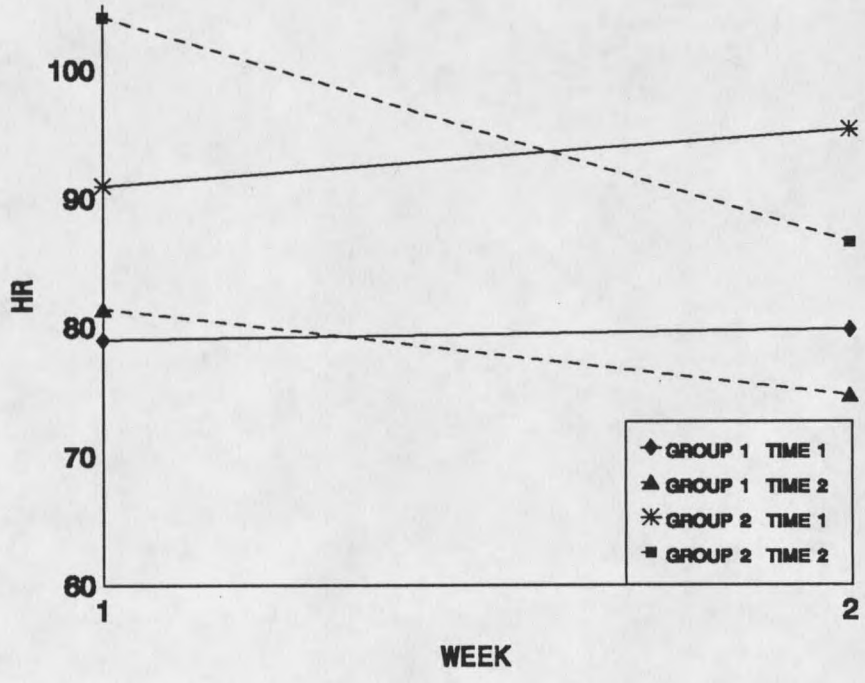


Figure 17. Week*Group*Time Interaction for HR.

and Time except the Group 1, Week 1, Time 2; and Group 2, Week 2, Time 2 combinations. This once more shows an order of testing effect on HR except for PM periods that were the second period within each week.

As with the Week*Time interaction, it was found that HR values for the first PM testing period were significantly greater than HR values for the second PM testing period for both Groups. Since the first and second PM periods occurred in different Weeks for both Groups, it can be concluded that the 7 to 10-day wait between Weeks 1 and 2 affect HR values in PM testing periods.

The first testing session was significantly greater than the second testing session each Week for Group 2, indicating that starting in a PM period the first Week and an AM period the second Week will result in greater HR values within each week for the first testing session.

It was also found for Group 2 that the first testing session in Week 1, PM, was significantly greater than their first testing session in Week 2, AM, indicating a within Group 2 order of testing effect.

RPE/HR Relationship

The Pearson Correlation Matrix in Appendix G and Figure 18 show little correlation between RPE and HR. Due to individual subject differences, the correlations between HR and RPE were calculated for each subject. These calculations

revealed that only one subject had a HR that correlated with RPE with a value of .65 or greater (Appendix G).

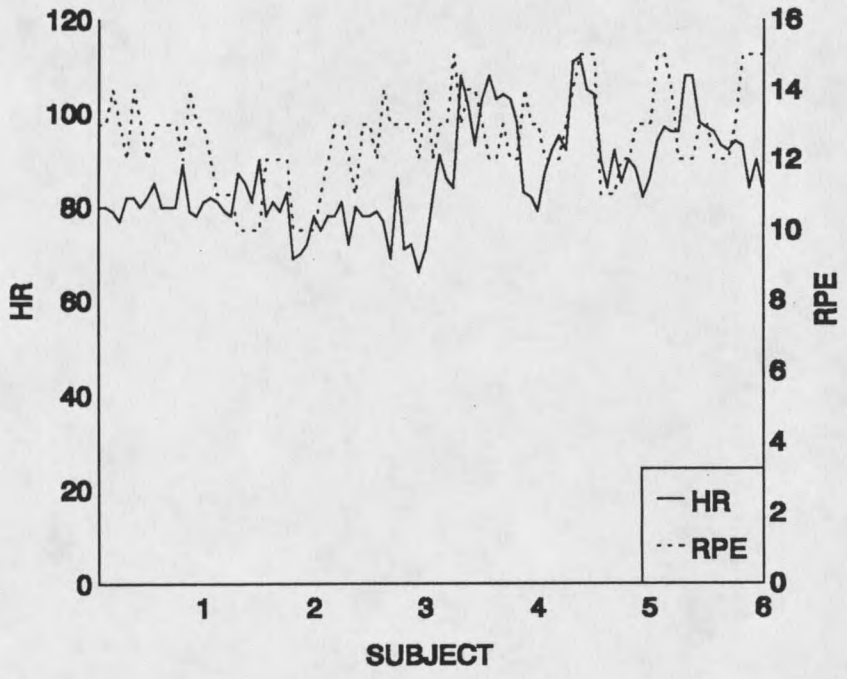


Figure 18. Subject HR/RPE Comparison.

The correlations for each subject for each testing session were next calculated (Appendix G). These calculations showed that HR and RPE correlated with a value of .65 or greater during eight of the twenty-four testing sessions with five of these correlations being negative. All of these negative correlations were in PM periods, four of which were in Group 2.

These data suggest that overall subjects were unable to correlate verbal anchors to the amount of physiological effort

they were exerting to perform the task. These results are similar to those found by Thompson and Chaffin (1993).

It is not surprising to find this lack of correlation. As stated earlier, HR is affected by many factors, other than workload, which were not controlled in this study. Subjects were instructed to rate the task based on the RPE scale, and it is unknown how well the demand caused by the task and these uncontrolled factors can be perceived when a localized upper extremity task is being evaluated.

It is also not surprising that MAF and RPE do not correlate (Appendix G). The testing criteria for method of adjustment and RPE studies are different, thus helping to explain why their values were not highly correlated.

RPE Analysis Residual analysis showed the errors in the RPE data to be normally distributed (Figures 19 and 20). The ANOVA for RPE, Table 15, found the Group*Week and Group*Time interactions to be significant effects.

The pattern shown in the in Residual Plot for RPE, Figure 19, can be explained by the fact that RPE is a discrete variable and ANOVA techniques assume the dependent variable is continuous. Precedence has been set in the literature for conducting ANOVA on RPE, (Marley and Fernandez (in press), Krawezyk et al. 1993 and Karwowski and Yates 1986), therefore, RPE was further analyzed using these techniques.

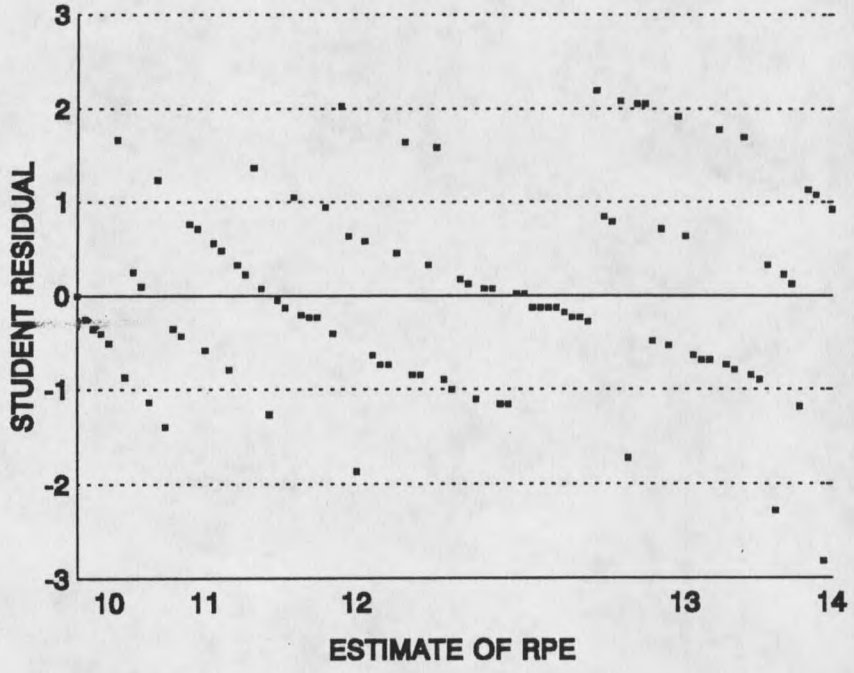


Figure 19. Residual Plot for RPE.

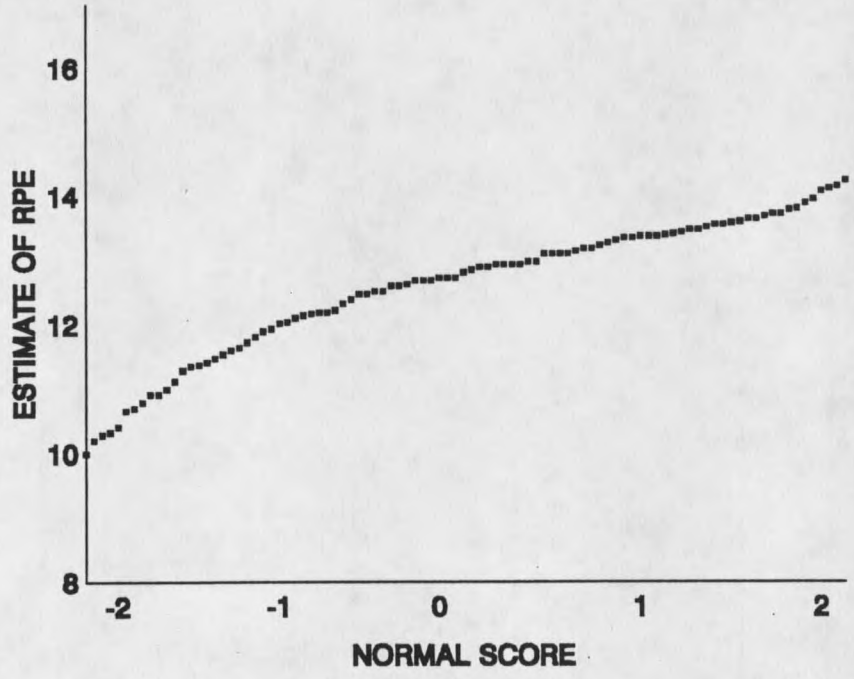


Figure 20. Normal Scores Plot for RPE.

Table 15. RPE ANOVA.

Model Variables

S = Subject
G = Group
W = Week
T = Time
B = Bout
RPE = Rating of Perceived Exertion

Categorical Variables S G W T B

Model $RPE = CONSTANT + G_i + S_{j(i)} + GS_{ij(i)} + W_k + T_l + B_m + GW_{ik} + GT_{il} + GB_{im} + WT_{kl} + WB_{km} + TB_{lm} + GWT_{ikl} + GWB_{ikm} + GTB_{ilm} + WTB_{klm} + \varepsilon_{n(ijklm)}$

Levels Encountered

S = 3
G = 2
W = 2
T = 2
B = 4

$R^2 = .623$

Analysis of Variance

Source	Sum-of-Squares	DF	Mean-Square	F-Ratio	P	
G_i	20.167	1	20.167	2.663	0.244	
$S_{j(i)}$	32.521	2	16.260	16.282	0.000	
$GS_{ij(i)}$	15.146	2	7.573	7.583	0.001	
W_k	0.375	1	0.375	0.375	0.542	
T_l	1.042	1	1.042	1.043	0.311	
B_m	4.042	3	1.347	1.349	0.267	
GW_{ik}	6.000	1	6.000	6.008	0.017	*
GT_{il}	16.667	1	16.667	16.689	0.000	*
GB_{im}	0.083	3	0.028	0.028	0.994	
WT_{kl}	2.042	1	2.042	2.044	0.158	
WB_{km}	0.875	3	0.292	0.292	0.831	
TB_{lm}	0.542	3	0.181	0.181	0.909	
GWT_{ikl}	2.667	1	2.667	2.670	0.107	
GWB_{ikm}	0.750	3	0.250	0.250	0.861	
GTB_{ilm}	0.750	3	0.250	0.250	0.861	
WTB_{klm}	0.375	3	0.125	0.125	0.945	
$\varepsilon_{n(ijklm)}$	62.917	63	0.999			

* Significant Variables that were Considered

A Tukey test performed on the Group*Week interaction found the level combinations shown in Appendix H to significantly differ from one another (Figures 21 and 22).

Group 2 had significantly greater RPE values than Group 1 for all combination levels within and between Weeks except for the Group 1, Week 2 with Group 2, Week 2 combination (Appendix G). Thus, indicating that the order of testing significantly affects RPE values. It is interesting to note

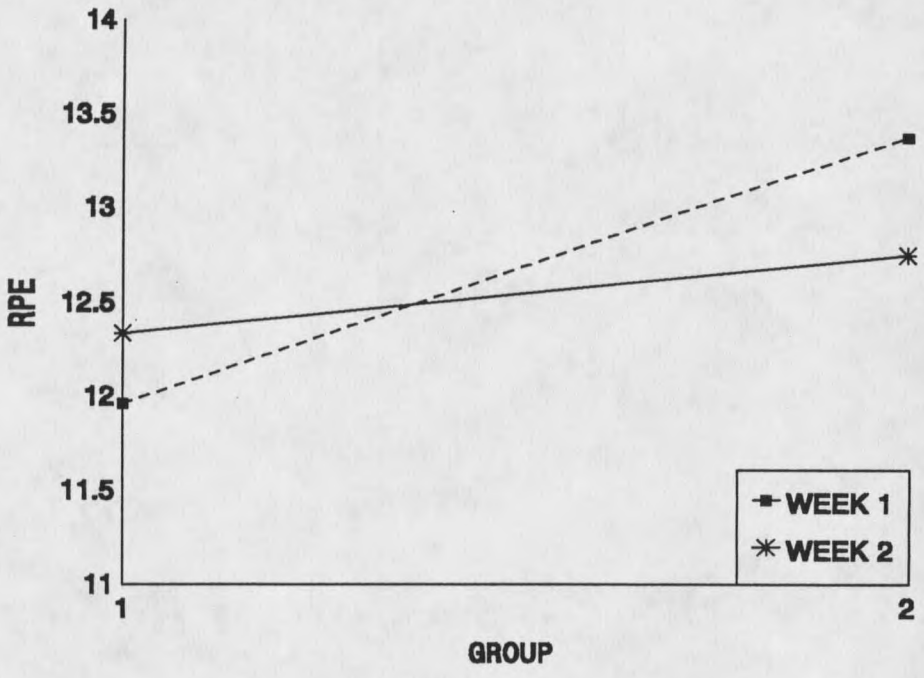


Figure 21. Group*Week Interaction for RPE.

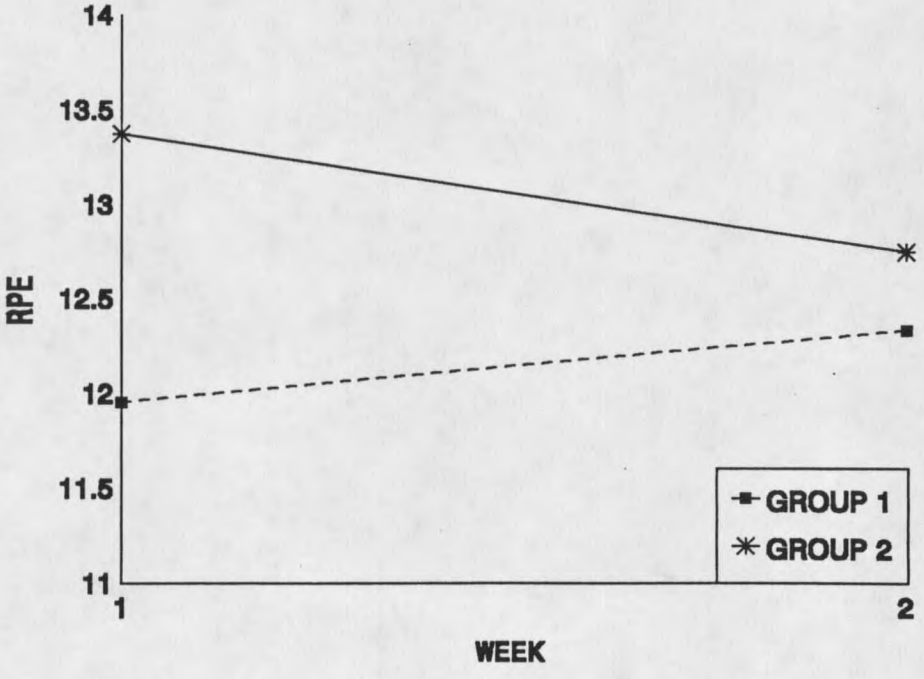


Figure 22. Week*Group Interaction for RPE.

that although no correlation was found, Group 2 also had the highest HR values.

A Tukey test was also performed on the Group*Time interaction which found the level combinations shown in Appendix H to be significantly different (Figures 23 and 24). The test showed the PM testing sessions for Group 2 resulted in significantly greater RPE values than any other combination

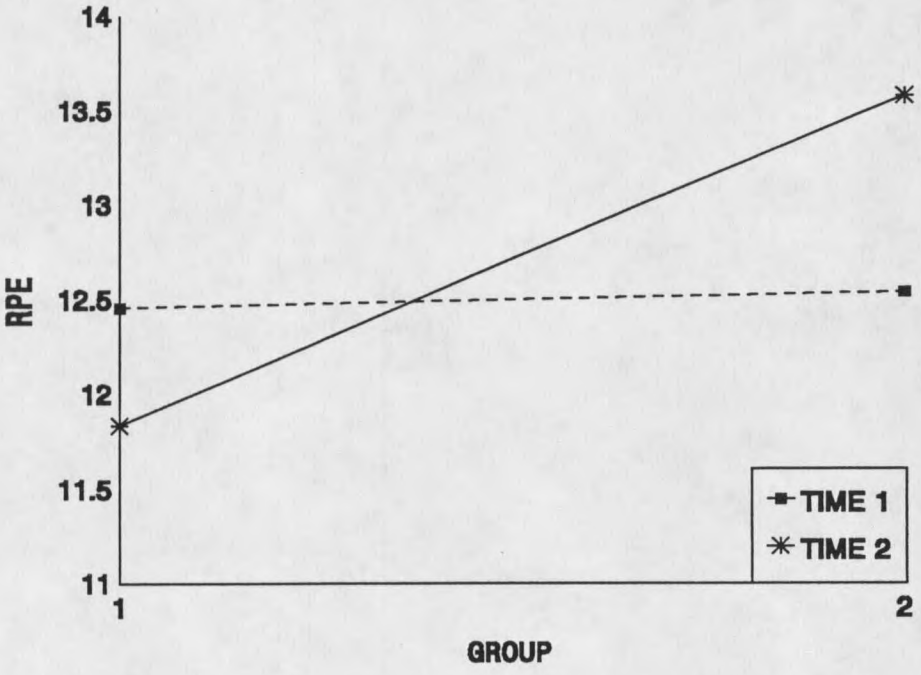


Figure 23. Group*Time Interaction for RPE.

of these two factors (Appendix H). Group 2's PM testing sessions were their first and last testing sessions. This indicates that PM periods combined with the order of testing results in significantly greater RPE values.

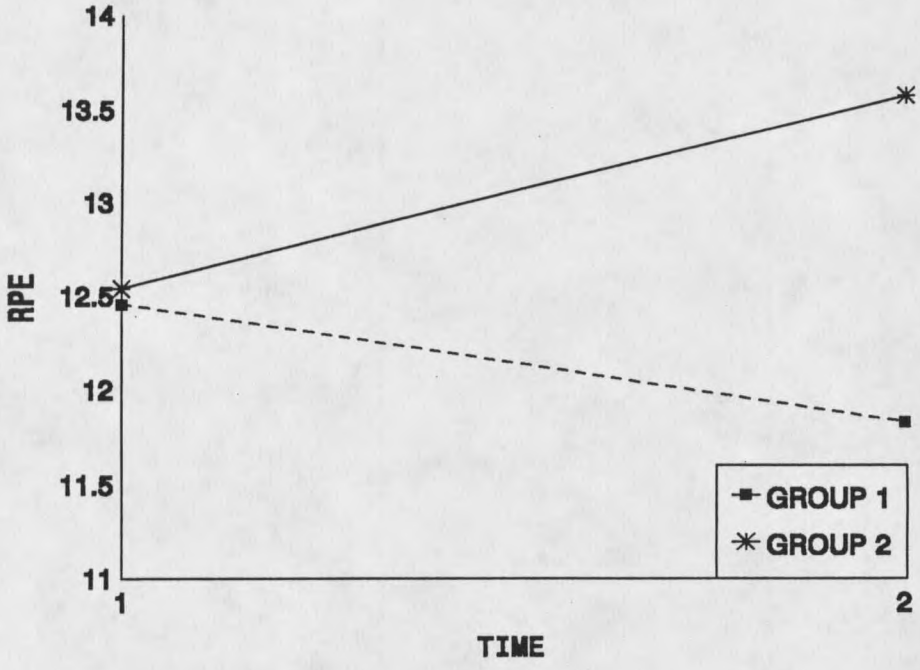


Figure 24. Time*Group Interaction for RPE.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following are the conclusions drawn based on the objectives stated:

1) The study found MAF to vary significantly between Weeks 1 and 2 of the experiment. It was concluded that this variation may have been due to uncontrolled factors. Although a significant difference was found, it is not believed it is meaningful in terms of work design, because the absolute difference between Weeks was 1.4 drills/minute and the relative difference was only 11.834%.

Bout 3 was found to significantly differ from Bout 1. However, the first and last Bouts each testing session were not significantly different. Based on this fact, it was concluded that the psychophysical method of adjustment can be used to reliably predict an MAF that can be maintained for a 2-hour period.

The ANOVA revealed that psychophysical reliability is not affected by the order of testing or the time of day. The

overall mean MAF and the mean MAF for Week 2 were not significantly different from published data.

2) Overall, the data showed no correlation between HR and MAF. Individually, half the subjects were able to perceive a greater overall physiological demand and adjust their MAF accordingly to reach a comfortable level.

Several factors other than MAF can affect HR and may account for the lack of correlation. Based on these facts, this study was inconclusive in determining the relationship between MAF and HR when using the method of adjustment for upper extremity work in perceiving physiological demands caused by the work load.

The data also found that subjects who conducted their first testing sessions in PM periods had consistently higher HR values than those who started in AM periods. This suggests that the time period in which the first testing session is conducted is critical and should be considered when designing an experiment.

Some subjects were able to perceive this greater overall physiological demand and selected lower MAF values in order to meet the "comfortable workload" criteria set forth in the subject instructions. Similar results were found between Weeks of testing and in the Week*Time and Group*Week*Time interactions.

3) The data showed that subjects were unable to assign verbal anchors to the physiological effort they were exerting

to perform the task. Once again, several factors influence HR besides MAF. Subjects were instructed to rate the task on the RPE scale based on how they perceived the task and it is unknown how well these uncontrolled HR influences are perceived and rated on the RPE scale when upper extremity localized tasks are being evaluated. The data also found the order of testing to significantly affect RPE values.

Recommendations

The following are recommendations for future research:

1) Future studies need to focus on extending the length of both testing sessions, up to 4 and 8-hours, and the time frame in which data are collected, over the course of a month. This is necessary to determine if 1 Bout can predict the MAF for 4 and 8-hour periods and to establish the learning curve and reliability of this method over extended periods of time.

2) Studies which take into account the factors that affect HR which were not controlled for in this study need to be conducted to establish a relationship between an objective criteria and the psychophysical method of adjustment used in upper extremity work. Suggested criteria which may not be as noisy as HR are breath-by-breath physiological measurements, biomechanical evaluation and electromyograph and blood pressure readings. Also, the effect of the pattern found in the order of testing should be further investigated for both HR and RPE.

3) The testing criteria for RPE is ratio estimation whereas for the psychophysical method of adjustment the criteria is adjustment. To determine the relationship between RPE and MAF for upper extremity work, a study which integrates these criteria would need to be conducted.

4) The effect of tool characteristics (ie. mass, center of mass and handle configuration) on MAF should be further explored to determine which characteristics correspond to the highest MAF values.

REFERENCES CITED

References

Armstrong, T.J. and D.B. Chaffin (1979). Some Biomechanical Aspects of the Carpal Tunnel. Biomechanics. 12, pp. 567-570.

Ayoub, M.M. (1987). The Problem of Manual Materials Handling. Trends in Ergonomics/Human Factors IV. Ed. by S.S. Asfour. Elsevier Science Publishers B.V. (North-Holland). pp. 901-907.

Ayoub, M.M., A. Mital, S.S. Asfour and N.J. Bethea (1980). Review, Evaluation, and Comparison of Models for Predicting Lifting Capacity. Human Factors. 22(3), pp. 257-269.

Borg, G. (1962). Physical Performance and Perceived Exertion. Gleerups, Lund.

Borg, G. (1970). Perceived Exertion as an Indicator of Somatic Stress. Scandinavian Journal of Rehabilitation Medicine. 2-3, pp. 92-98.

Borg, G. (1971). The Perception of Physical Performance. Frontiers of Fitness. Ed. by R.J. Shephard, C.C. Thomas. Springfield, Illinois. pp. 280-294.

Borg, G. (1982). Psychophysical Bases of Perceived Exertion. Medicine and Science in Sports and Exercise. 14(5), pp. 377-381.

Chaffin, D.B. (1975). Ergonomics Guide for the Assessment of Human Static Strength. American Industrial Hygiene Association Journal. 36, pp. 505-510.

Ciriello, V.M. and S.H. Snook (1983). A Study of Size, Distance, Height, and Frequency Effects on Manual Handling Tasks. Human Factors. 25(5), pp. 473-483.

Collier, R.O. Jr. and T.J. Hummel (1977). Experimental Design and Interpretation. Berkeley, California: McCutchan Publishing Corporation.

Corlett, E.N. and R.P. Bishop (1976). A Technique for Assessing Postural Discomfort. Ergonomics. 19(2), pp. 175-182.

Davis, P.J. (1992). Maximum Acceptable Frequencies for Females Performing a Drilling Task in Four Wrist Postures. Unpublished M.S. Thesis. The Wichita State University, Wichita, Kansas.

Fechner, G.T. (1860). Element der Psychophysik. Leipzig: Breitkopf & Härterl.

Feldman, R.G., R.G. Goldman and W.M. Keyserling (1983). Peripheral Nerve Entrapment Syndromes and Ergonomics Factors. American Journal of Industrial Medicine. 4, pp. 661-681.

Fernandez, J.E. (1986). Psychophysical Lifting Capacity Over Extended Periods. Unpublished Ph.D. dissertation. Texas Tech University, Lubbock, Texas.

Fernandez, J.E. and M.M. Ayoub (1988). The Psychophysical Approach: The Valid Measure of Lifting Capacity. Trends in Ergonomics/Human Factors V. Ed. F. Aghazadeh. Elsevier Science Publishers B.V. (North-Holland).

Fernandez, J.E., R.J. Marley and K.R. Young (1990). Results of Ongoing Monitoring Program for Carpal Tunnel Syndrome. Advances in Industrial Ergonomics and Safety II. Ed. by Biman Das. London: Taylor & Francis, pp. 265-272.

Fernandez, J.E., M.M. Ayoub and J.L. Smith (1991). Psychophysical Lifting Capacity Over Extended Periods. Ergonomics. 34(1), pp. 23-32.

Fernandez, J.E., J.B. Dahalan, M.G. Klein and R.J. Marley (1993). Using the Psychophysical Approach in Hand-Wrist Work. Proceedings of the M.M. Ayoub Occupational Ergonomics Symposium. pp.63-70.

Foreman, T.K., C.E. Baxter and J.D.G. Troop (1984). Ratings of Acceptable Load and Maximal Isometric Lifting Strengths: the Effects of Repetition. Ergonomics. 27(12), pp. 1283-1288.

Gamberale, F. (1985). The Perception of Exertion. Ergonomics. 28(1), pp.299-308.

Gamberale, F., A.S. Ljungberg, G. Annwall and A. Kilbom (1987). An Experimental Evaluation of Psychophysical Criteria for Repetitive Lifting Work. Applied Ergonomics. 18.4, pp. 311-321.

Genaidy, A.M., A. Mital and K.M. Bafna (1989). An Endurance Training Programme for Frequent Manual Carrying Tasks. Ergonomics. 32(2), pp. 149-155.

Gescheider, G.A. (1985). Psychophysics: Method, Theory, and Application, 2nd ed. Hillsdale, New Jersey: Lawrence Erlbuum Associates.

Griffin, A.B., J.D.G. Troup and D.C.E.F. Lloyd (1984). Tests of Lifting and Handling Capacity. Their Repeatability and Relationship to Back Symptoms. Ergonomics. 27(3), pp. 305-320.

Griffith, J.W., W.A. Kerr, T.B. Mayo, Jr. and J.R. Topel (1950). Changes in Subjective Fatigue and Readiness for Work During the Eight-Hour Shift. Journal of Applied Psychology. 34, pp. 163-166.

Hicks, C.R. (1982). Fundamental Concepts in the Design of Experiments 3rd ed. New York: Holt, Rinehart and Winston.

Karwowski, W. (1983). A Pilot Study of the Intersection Between Physiological, Biomechanical and Psychophysical Stresses Involved in Manual Lifting Activities. Proceedings of the Ergonomics Society's 1983 Conference. Ed. by K. Coombs. London: Taylor & Francis, Ltd. pp. 95-100.

Karwowski, W. and M.M. Ayoub (1984). Effect of Frequency on the Maximum Acceptable Weight of Lift. Trends in Ergonomics/Human Factors I. Elsevier Science Publishers B.V. (North-Holland), pp. 167-172.

Karwowski, W. and J.W. Yates (1986). Reliability of the Psychophysical Approach to Manual Lifting of Liquids by Females. Ergonomics. 29(2), pp. 237-248.

Krawezyk, S., T.J. Armstrong and S.H. Snook (1993). Psychophysical Assessment of Simulated Assembly Line Work: Combinations of Transferring and Screw Driving Tasks. Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting. Human Factors and Ergonomics Society,.pp. 803-807.

Kroemer, K.H.E. (1989). Cumulative Trauma Disorders: Their Recognition and Ergonomics Measures to Avoid Them. Applied Ergonomics. 20.4, pp. 274-280.

Legg, S.T. and W.S. Myles (1985). Metabolic and Cardiovascular Cost, and Perceived Effort Over an 8 Hour Day When Lifting Loads Selected by the Psychophysical Method. Ergonomics. 28(1), pp. 337-343.

LeVeau, B., Williams and Lissner (1977). Biomechanics of Human Motion. Saunders, Philadelphia.

Ljungberg, A.S., F. Gamberale and A. Kilbom (1982). Horizontal Lifting - Physiological and Psychophysical Responses. Ergonomics. 25(8), pp. 741-757.

Marley, R.J. (1990). Psychophysical Frequency at Different Wrist Postures of Females for a Drilling Task. Unpublished Ph.D. dissertation. The Wichita State University, Wichita, Kansas.

Marley, R.J. and J.E. Fernandez (in press). Psychophysical Frequency and Static Exertion at Varying Wrist Postures for a Drilling Task. Ergonomics.

Mathiowetz, V., K. Weber, G. Volland and N. Kashman (1984). Reliability and Validity of Grip and Pinch Strength Evaluations. The Journal of Hand Surgery. 9A(2), pp. 222-226.

Mathiowetz, V., N. Kashman, G. Volland, K. Weber, M. Dowe and S. Rogers (1985). Grip and Pinch Strength: Normative Data for Adults. Archives of Physical and Medical Rehabilitation. 66, pp. 66-74.

Mihevic, P.M. (1981). Sensory Cues for Perceived Exertion: a Review. Medicine and Science in Sports and Exercise. 13(3), pp. 150-163.

Mital, A. (1983). The Psychophysical Approach in Manual Lifting-A Verification Study. Human Factors. 25(5), pp. 485-491.

Mital, A. (1986). Comparison of Lifting Capabilities of Industrial and Non-Industrial Populations. Proceedings of the Human Factors Society 30th Annual Meeting. Santa Monica, Ca., pp. 239-241.

Mital, A., W. Karwowski and A.K. Chalaka (1987). A Laboratory Simulation of Self-Paced and Force-Paced Industrial Stacking and Palletizing Tasks. Journal of Human Ergology. 16, pp. 31-41.

Montgomery, D.C. (1984). Design & Analysis of Experiments. New York: John Wiley & Sons.

Phalen, G.S. (1966). The Carpel Tunnel Syndrome. The Journal of Bone and Joint Surgery. 48-A(2), pp. 221-228.

Pheasant, S. (1986). Bodyspace: Anthropometry, Ergonomics and Design. Philadelphia: Taylor & Francis.

Putz-Anderson, V. (1988). Cumulative Trauma Disorders: A Manual for Musculoskeletal Diseases of the Upper Limbs. NIOSH. New York: Taylor & Francis.

Sharp, M.A. and S.J. Legg (1988). Effects of Psychophysical Lifting Training on Maximal Repetitive Lifting Capacity. American Industrial Hygiene Association Journal. 49(12), pp. 639-644.

Snook, S.H. (1978). The Design of Manual Handling Tasks. Ergonomics. 21(12), pp. 963-985.

Snook, S.H. (1985). Psychophysical Considerations in Permissible Loads. Ergonomics. 28(1), pp. 327-330.

Snook, S.H. and C.H. Irvine (1967). Maximum Acceptable Weight of Lift. American Industrial Hygiene Association Journal. 28, pp. 322-329.

Snook, S.H. and C.H. Irvine (1968). Maximum Frequency of Lift Acceptable to Male Industrial Workers. American Industrial Hygiene Association Journal. 29, pp. 531-536.

Snook, S.H., C.H. Irvine and S.F. Bass (1970). Maximum Weights and Workloads Acceptable to Male Industrial Workers. American Industrial Hygiene Association Journal. 31, pp. 579-586.

Snook, S.H. and V.M. Ciriello (1974). Maximum Weights and Work Loads Acceptable to Female Workers. Journal of Occupational Medicine. 16(8), pp. 527-534.

Stevens, S.S. (1958). Problems and Methods of Psychophysics. Psychophysical Bulletin. 55(4), pp. 177-196.

Stevens, S.S. (1986). Psychophysics: Introduction to its Perceptual, Neural, and Social Prospects. Ed. by Geraldine Stevens. New Brunswick: Transaction Books.

Tanaka, S., P. Seligman, W. Halperin, M. Thun, C.L. Timbrook and J.J. Wasil (1988). Use of Workers' Compensation Claims Data for Surveillance of Cumulative Trauma Disorders (CTD's). Journal of Occupational Medicine. 30(6), pp. 488-492.

Tanaka, S. and J.D. McGlothlin (1993). A Conceptual Quantitative Model for Prevention of Work-Related Carpel Tunnel Syndrome (CTS). International Journal of Industrial Ergonomics. 11, pp. 181-193.

Thompson, D.D. and D.B. Chaffin (1993). Can Biomechanically Determined Stress be Perceived? Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting. Human Factors and Ergonomics Society. pp. 789-792.

APPENDICES

Appendix A

Scales, Forms and Questionnaires

Borg Scale

6

7 Very very light

8

9 Very light

10

11 Fairly light

12

13 Somewhat hard

14

15 Hard

16

17 Very hard

18

19 Very very hard

20

Figure 25. Fifteen Point Borg RPE Scale. Source: Borg (1970)

CTD/Medical History Screen

Subject #: 1 2 3 Group #: 1 2

Phalen's Test + / -

Check if answer is yes only. Leave others blank.

_____ Have you ever been diagnosed with carpel tunnel syndrome or any other cumulative trauma disorder?

_____ Do you ever experience abnormal heartbeats, have pain in your chest or heart?

_____ Do you sometimes experience difficulty breathing?

_____ Do you experience recurring pain in the shoulders, elbows, wrists or hands?

_____ Do you have significant vision or hearing problems?

MONTANA STATE UNIVERSITY
1893-CENTENNIAL-1993

Department of Industrial and Management Engineering

College of Engineering
Montana State University
Bozeman, MT 59717-03843

Telephone 406-994-3971

Informed Consent

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH

You are invited to participate in a study titled "A Verification Study of the Psychophysical Method for Upper Extremity Work." This study will examine the use of a subjective method (the psychophysical approach) to determine the reliability and its association to objective criteria in applying it to upper extremity work. The results of this study are expected to aid industrial engineers in determining task testing criteria. This may ultimately lead to a reduced risk of cumulative trauma disorders (CTD) such as carpal tunnel syndrome (CTS) for workers.

If you decide to participate and are accepted, you will be required to perform a simulated sheet metal drilling task. This consists of using a hand-held drill and applying a specified force to a target hole for a given length of time. The rate of this task will be chosen by you and is defined as a "comfortable" frequency. For safety, the actual drill is not connected to power and the drill bit is non-functional (no cutting edge). Including a familiarization session, you will be expected to participate for a total of 10 hours of observations spread over 3 weeks.

You will be required to complete a questionnaire regarding your medical history. Certain bodily measurements will be taken such as neutral grip and pinch strengths and anthropometric measurements including height, weight and elbow height. During performance of the simulated task, measurements of heart rate, frequency and your perceived exertion on a standardized scale will be recorded.

Because this task is simulated using a non-functional tool, you should not experience any unusual discomfort nor risk of injury resulting from the equipment or procedures.

Because the task involves the musculature of the upper extremities, however, you may experience some minor soreness in these muscles and/or stiffness in the involved joints. The I&ME Department or Montana State University cannot provide compensation for such conditions or any other health problems that might arise as a result of this experiment.

If you decide to participate, you will not be compensated for your involvement. Your participation is completely voluntary. You may choose to withdraw from participation at any time. Such a withdrawal will not affect your relationship, if any, with the I&ME Department or with Montana State University. All information obtained during this study by which you could be identified will be held in strict confidence.

If at any time you have questions regarding this research, you may contact either Mike Willis, 21D Ryon Lab, 994-6994 or Dr. Robert Marley, Industrial & Management Engineering Dept., 315 Robert Hall, Montana State University, Bozeman, MT, 59717, (406) 994-3971.

By placing your signature below, you are indicating that you have read all the above information, are willing to participate and free the conductors of this study from any liabilities that may incur.

Signature of Participant _____ Date _____

Signature of Investigator _____ Date _____

Subject Instructions

I am attempting to find out the maximum acceptable frequency at which an individual can be expected to perform a drilling task comfortably and without strain.

I want you to imagine you are drilling pilot holes in sheet metal. You are getting paid on a piecework basis, but are working a normal 8-hour shift with normal breaks that allows you to go home without feeling bushed. In other words, you are to work as hard as you can without straining yourself, or without becoming unusually tired, weakened, overheated or out of breath.

You will adjust your own workload. You will work only when you hear the beep. Sometimes the beep will have you working fast; sometimes slow. Your job will be to adjust the frequency.

Adjusting your own workload is not an easy task. Only you know how you feel. If you feel you are working too hard, reduce the frequency by turning the knob counterclockwise. I don't want you loafing either. If you feel you can work harder, increase the frequency by turning the knob clockwise. Don't be afraid to make adjustments.

You have to make enough adjustments so that you get a good feeling for what is too fast and what is too slow. Be very conscience of your own feelings and make adjustments accordingly. You can never make too many adjustments - but you can make too few.

REMEMBER....
THIS IS NOT A CONTEST.
EVERYONE IS NOT EXPECTED TO DRILL AT THE SAME FREQUENCY.
I WANT YOUR ESTIMATION ON HOW FAST YOU CAN DRILL WITHOUT BECOMING UNUSUALLY TRIED.

Your adjustment period will last for 20 minutes. The frequency set at the end of the adjustment period will be maintained for an additional 5 minutes. A 5 minute rest period will then be allowed, then the cycle will repeat. Four cycles will be performed each testing session.

Data Collection Form

Name:	Phone:	Age:
Dominant Hand: R L	Sex: M F	Elbow Height: cm
Stature: cm	Weight: kg	Grip: kg	Pinch: kg

Subject #: 1 2 3 Group #: 1 2

AM DATE			WEEK 1		PM DATE
BOUT 1		HR bts/min	BOUT 1		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE
2		HR bts/min	2		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE
3		HR bts/min	3		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE
4		HR bts/min	4		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE

AM DATE			WEEK 2		PM DATE
BOUT 1		HR bts/min	BOUT 1		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE
2		HR bts/min	2		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE
3		HR bts/min	3		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE
4		HR bts/min	4		HR bts/min
Starting Freq.		FREQ /min	Starting Freq.		FREQ /min
		RPE			RPE

Figure 26. Data Collection Form.

Table 16. Random Numbers.

data cell # /subject #	random # for cell	random # for subject	data cell #	random # for cell	data cell #	random # for cell
1	0	0	33	5	65	9
2	3	9	34	8	66	10
3	3	4	35	0	67	10
4	1	7	36	4	68	9
5	5	1	37	6	69	9
6	7	2	38	5	70	7
7	5		39	3	71	9
8	3		40	7	72	8
9	3		41	5	73	3
10	3		42	7	74	9
11	8		43	3	75	4
12	6		44	1	76	3
13	1		45	9	77	1
14	1		46	6	78	5
15	3		47	3	79	9
16	8		48	6	80	8
17	4		49	1	81	4
18	2		50	10	82	4
19	5		51	7	83	9
20	3		52	7	84	6
21	1		53	8	85	4
22	9		54	5	86	7
23	8		55	3	87	7
24	2		56	4	88	1
25	4		57	5	89	7
26	6		58	2	90	2
27	8		59	8	91	5
28	8		60	10	92	5
29	8		61	4	93	6
30	2		62	2	94	5
31	1		63	9	95	4
32	5		64	1	96	4

APPENDIX B

Subject Analysis

Table 17. Subject Data.

SUBJECT	AGE	ELBOW HEIGHT	STATURE	WEIGHT	GRIP STRENGTH	PINCH STRENGTH
1	23	114	178.0	81	59.00	12.50
2	29	113	176.0	73	55.70	11.70
3	22	114.5	179.0	75	54.00	9.70
4	23	118	189.0	76	45.00	11.67
5	23	116.5	183.0	84	70.67	12.83
6	25	114.5	178.5	110	47.00	10.42

Mean Test for Stature

1. *Null hypothesis:* $\mu = 175.5$
   Alternative hypothesis: $\mu \neq 175.5$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.571$ or $t > 2.571$, where 2.571 is the value of $t_{0.025}$ for $6 - 1 = 5$ degrees of freedom and

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

4. *Calculations:*

$$t = \frac{180.583 - 175.500}{4.716/\sqrt{6}} = 2.640$$

5. *Decision:* Since $t = 2.640$ is greater than 2.571, the null hypothesis must be rejected at level $\alpha = 0.05$.

Mean Test for Elbow Height

1. *Null hypothesis:* $\mu = 110.5$
   Alternative hypothesis: $\mu \neq 110.5$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.571$ or $t > 2.571$, where 2.571 is the value of $t_{0.025}$ for $6 - 1 = 5$ degrees of freedom and

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

4. *Calculations:*

$$t = \frac{115.083 - 110.500}{1.828/\sqrt{6}} = 6.142$$

5. *Decision:* Since $t = 6.142$ is greater than 2.571, the null hypothesis must be rejected at level $\alpha = 0.05$.

Mean Test for Weight

1. *Null hypothesis:* $\mu = 76.360$
   Alternative hypothesis: $\mu \neq 76.360$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.571$ or $t > 2.571$, where 2.571 is the value of $t_{0.025}$ for $6 - 1 = 5$ degrees of freedom and

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

4. *Calculations:*

$$t = \frac{83.167 - 76.360}{13.761/\sqrt{6}} = 1.212$$

5. *Decision:* Since $t = 1.212$ is less than 2.571, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test for Grip Strength

1. *Null hypothesis:* $\mu = 55$
   Alternative hypothesis: $\mu \neq 55$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.571$ or $t > 2.571$, where 2.571 is the value of $t_{0.025}$ for $6 - 1 = 5$ degrees of freedom and

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

4. *Calculations:*

$$t = \frac{55.228 - 55.000}{9.238/\sqrt{6}} = 0.061$$

5. *Decision:* Since $t = 0.061$ is less than 2.571, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test for Pinch Strength

1. *Null hypothesis:* $\mu = 12.090$
   Alternative hypothesis: $\mu \neq 12.090$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.571$ or $t > 2.571$, where 2.571 is the value of $t_{0.025}$ for $6 - 1 = 5$ degrees of freedom and

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

4. *Calculations:*

$$t = \frac{11.470 - 12.090}{1.203/\sqrt{6}} = -1.262$$

5. *Decision:* Since $t = -1.262$ is greater than -2.571, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Subject Measures Correlation Matrix

	EH	STAT	W	G	P
EH	1.000				
STAT	0.985	1.000			
W	-0.056	-0.151	1.000		
G	-0.089	-0.191	-0.216	1.000	
P	0.233	0.220	-0.225	0.607	1.000

Mean Test for Stature Between Groups

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if t < -2.776 or t > 2.776, where 2.776 is the value of $t_{0.025}$ for 3 + 3 - 2 = 4 degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(179.000 - 182.167)}{\sqrt{(3-1)(3.606)^2 + (3-1)(5.923)^2}} \sqrt{\frac{(3)(3)(3+3-2)}{3+3}} = -0.791$$

5. *Decision:* Since t = -0.791 is greater than -2.776, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test for Elbow Height Between Groups

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.776$ or $t > 2.776$, where 2.776 is the value of $t_{0.025}$ for $3 + 3 - 2 = 4$ degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(114.500 - 115.667)}{\sqrt{(3-1)(1.803)^2 + (3-1)(2.021)^2}} \sqrt{\frac{(3)(3)(3+3-2)}{3+3}} = -0.746$$

5. *Decision:* Since $t = -0.746$ is greater than -2.776, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test for Weight Between Groups

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.776$ or $t > 2.776$, where 2.776 is the value of $t_{0.025}$ for $3 + 3 - 2 = 4$ degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(79.333 - 87.000)}{\sqrt{(3-1)(5.686)^2 + (3-1)(19.925)^2}} \sqrt{\frac{(3)(3)(3+3-2)}{3+3}} = -0.641$$

5. *Decision:* Since $t = -0.641$ is greater than -2.776, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test for Grip Strength Between Groups

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.776$ or $t > 2.776$, where 2.776 is the value of $t_{0.025}$ for $3 + 3 - 2 = 4$ degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(61.790 - 48.667)}{\sqrt{(3-1)\,(7.865)^2 + (3-1)\,(4.726)^2}} \sqrt{\frac{(3)\,(3)\,(3+3-2)}{3+3}} = 2.477$$

5. *Decision:* Since $t = 2.477$ is less than 2.776, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test for Pinch Strength Between Groups

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.776$ or $t > 2.776$, where 2.776 is the value of $t_{0.025}$ for $3 + 3 - 2 = 4$ degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(12.343 - 10.597)}{\sqrt{(3-1)\,(0.581)^2 + (3-1)\,(0.997)^2}} \sqrt{\frac{(3)\,(3)\,(3+3-2)}{3+3}} = 2.622$$

5. *Decision:* Since $t = 2.622$ is less than 2.776, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

APPENDIX C

Dependent Variable Values

Table 18. Raw Data.

Subject	Group	Week	Time	Bout	RPE	HR	FREQ
1	1	1	1	1	13	80	9.63
1	1	1	1	2	13	80	8.72
1	1	1	1	3	14	79	11.07
1	1	1	1	4	13	77	8.84
1	1	1	2	1	12	82	9.29
1	1	1	2	2	14	82	9.80
1	1	1	2	3	13	80	9.76
1	1	1	2	4	12	82	9.27
1	1	2	1	1	13	85	10.08
1	1	2	1	2	13	80	9.08
1	1	2	1	3	13	80	9.72
1	1	2	1	4	13	80	9.80
1	1	2	2	1	12	89	9.20
1	1	2	2	2	14	79	11.17
1	1	2	2	3	13	78	9.20
1	1	2	2	4	13	81	9.70
2	1	1	1	1	12	82	16.35
2	1	1	1	2	11	81	16.35
2	1	1	1	3	11	79	16.35
2	1	1	1	4	11	78	16.35
2	1	1	2	1	10	87	16.22
2	1	1	2	2	10	85	15.96
2	1	1	2	3	10	81	15.96
2	1	1	2	4	10	90	16.00
2	1	2	1	1	12	78	17.05
2	1	2	1	2	12	81	17.39
2	1	2	1	3	12	79	16.57
2	1	2	1	4	12	83	16.67
2	1	2	2	1	10	69	18.58
2	1	2	2	2	10	70	17.24
2	1	2	2	3	10	72	17.60
2	1	2	2	4	10	78	18.18
3	1	1	1	1	11	75	10.33
3	1	1	1	2	12	78	10.88
3	1	1	1	3	13	78	12.53
3	1	1	1	4	13	81	11.36
3	1	1	2	1	12	72	11.88
3	1	1	2	2	11	80	12.88
3	1	1	2	3	13	78	14.02

Table 18. Continued.

3	1	1	2	4	13	78	13.70
3	1	2	1	1	12	79	13.13
3	1	2	1	2	14	77	15.38
3	1	2	1	3	13	69	13.54
3	1	2	1	4	13	86	14.22
3	1	2	2	1	13	71	13.67
3	1	2	2	2	13	72	13.51
3	1	2	2	3	12	66	13.25
3	1	2	2	4	14	71	14.49
1	2	1	1	1	12	82	8.58
1	2	1	1	2	13	91	10.79
1	2	1	1	3	13	86	9.87
1	2	1	1	4	15	84	11.07
1	2	1	2	1	13	108	12.88
1	2	1	2	2	14	102	11.41
1	2	1	2	3	14	93	12.77
1	2	1	2	4	13	103	12.00
1	2	2	1	1	12	108	12.22
1	2	2	1	2	12	103	10.05
1	2	2	1	3	13	104	16.53
1	2	2	1	4	12	103	11.79
1	2	2	2	1	12	98	11.03
1	2	2	2	2	14	83	11.74
1	2	2	2	3	13	82	14.63
1	2	2	2	4	13	79	13.76
2	2	1	1	1	12	87	9.57
2	2	1	1	2	12	92	9.66
2	2	1	1	3	12	95	10.00
2	2	1	1	4	13	92	9.40
2	2	1	2	1	14	111	8.39
2	2	1	2	2	15	112	8.96
2	2	1	2	3	15	105	9.63
2	2	1	2	4	15	104	9.68
2	2	2	1	1	11	90	9.40
2	2	2	1	2	11	84	9.79
2	2	2	1	3	11	92	10.70
2	2	2	1	4	12	85	10.70
2	2	2	2	1	12	90	11.17
2	2	2	2	2	13	88	11.17
2	2	2	2	3	13	82	11.69
2	2	2	2	4	13	86	12.17

Table 18. Continued.

3	2	1	1	1	15	94	13.70
3	2	1	1	2	15	97	14.18
3	2	1	1	3	14	96	14.35
3	2	1	1	4	12	96	13.61
3	2	1	2	1	12	108	8.80
3	2	1	2	2	12	108	10.17
3	2	1	2	3	13	98	12.77
3	2	1	2	4	13	97	12.47
3	2	2	1	1	12	96	12.55
3	2	2	1	2	12	93	13.33
3	2	2	1	3	12	92	13.64
3	2	2	1	4	13	94	15.50
3	2	2	2	1	15	93	14.63
3	2	2	2	2	15	84	16.71
3	2	2	2	3	15	90	18.35
3	2	2	2	4	15	84	13.82

APPENDIX D

Reliability Data

% Difference Between Weeks for MAF

(13.239 - 11.838) / 11.838 = 11.834%

Test Between Overall and Subject Variances

1. *Null hypothesis:* $\sigma_1^2 = \sigma_2^2$
   Alternative hypothesis: $\sigma_1^2 \neq \sigma_2^2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if F > 4.413, the value of $F_{0.05}$ for 95 and 5 degrees of freedom, where

$$F = \frac{s_2^2}{s_2^1}$$

4. *Calculations:*

$$F = \frac{(2.79)^2}{(2.616)^2} = 1.137$$

5. *Decision:* Since F = 1.137 is less than 4.413, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Pooled Variance

$$\sigma^2 = \frac{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}{n_1 + n_2 - 2}$$

$$\sigma^2 = \frac{(15-1)\,(3.020)^2 + (6-1)\,(2.616)^2}{15+6-2} = 8.521$$

$$\sigma = 2.912$$

Weighted Mean

$$\mu = \frac{(6)(12.539)+(15)(14.800)}{21} = 14.154$$

Confidence Interval

$$14.154-(2.086)\left(\frac{2.912}{\sqrt{21}}\right)<\mu<14.154+(2.086)\left(\frac{2.912}{\sqrt{21}}\right)$$

$$12.828 < \mu < 15.480$$

Tukey Test on Bout for MAF

Row	B
1	1
2	2
3	3
4	4

Matrix of Pairwise Comparison Probabilities

	1	2	3	4
1	1.000			
2	0.785	1.000		
3	0.016 *	0.154	1.000	
4	0.238	0.770	0.650	1.000

* Significant

Mean Test for Days of Testing

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.01$

3. *Criterion:* Reject the null hypothesis if $t < -2.576$ or $t > 2.576$, where 2.576 is the value of $t_{0.005}$ for $24 + 24 - 2 = 46$ degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(13.479 - 11.612)}{\sqrt{(24-1)(2.737)^2 + (24-1)(2.583)^2}} \sqrt{\frac{(24)(24)(24+24-2)}{24+24}} = 2.431$$

5. *Decision:* Since $t = 2.431$ is less than 2.576, the null hypothesis cannot be rejected at level $\alpha = 0.01$.

Mean Test Between Published and Overall MAF

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.093$ or $t > 2.093$, where 2.093 is the value of $t_{0.005}$ for $15 + 6 - 2 = 21$ degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(14.800 - 12.539)}{\sqrt{(15-1)(3.02)^2 + (6-1)(2.616)^2}} \sqrt{\frac{(15)(6)(15+6-2)}{15+6}} = 1.603$$

5. *Decision:* Since $t = 1.603$ is less than 2.093, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

Mean Test Between Published and Week 1 MAF

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.093$ or $t > 2.093$, where 2.093 is the value of $t_{0.005}$ for 15 + 6 - 2 = 21 degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(14.800 - 11.838)}{\sqrt{(15-1)(3.02)^2 + (6-1)(2.567)^2}} \sqrt{\frac{(15)(6)(15+6-2)}{15+6}} = 2.109$$

5. *Decision:* Since t = 2.109 is greater than 2.093, the null hypothesis must be rejected at level $\alpha = 0.05$.

Mean Test Between Published and Week 2 MAF

1. *Null hypothesis:* $\mu_1 = \mu_2$
   Alternative hypothesis: $\mu_1 \neq \mu_2$

2. *Level of significance:* $\alpha = 0.05$

3. *Criterion:* Reject the null hypothesis if $t < -2.093$ or $t > 2.093$, where 2.093 is the value of $t_{0.005}$ for 15 + 6 - 2 = 21 degrees of freedom and

$$t = \frac{(\overline{x_1} - \overline{x_2}) - \delta}{\sqrt{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

4. *Calculations:*

$$t = \frac{(14.800 - 13.239)}{\sqrt{(15-1)(3.02)^2 + (6-1)(2.852)^2}} \sqrt{\frac{(15)(6)(15+6-2)}{15+6}} = 1.086$$

5. *Decision:* Since t = 1.086 is less than 2.093, the null hypothesis cannot be rejected at level $\alpha = 0.05$.

APPENDIX E

HR/MAF Relationship Data

Pearson Correlation Matrix for HR and MAF

	MAF	HR
MAF	1.000	
HR	-0.277	1.000

Individual HR by MAF Correlation Matrices

S = 1
G = 1

	HR	MAF
HR	1.000	
MAF	-0.088	1.000

S = 2
G = 2

	HR	MAF
HR	1.000	
MAF	-0.680	1.000

S = 1
G = 2

	HR	MAF
HR	1.000	
MAF	0.160	1.000

S = 3
G = 1

	HR	MAF
HR	1.000	
MAF	-0.068	1.000

S = 2
G = 1

	HR	MAF
HR	1.000	
MAF	-0.737	1.000

S = 3
G = 2

	HR	MAF
HR	1.000	
MAF	-0.792	1.000

Individual HR by MAF Correlations for each Testing Period

S = 1
G = 1
W = 1
T = 1

	HR	MAF
HR	1.000	
MAF	0.146	1.000

S = 1
G = 2
W = 1
T = 1

	HR	MAF
HR	1.000	
MAF	0.582	1.000

S = 1
G = 1
W = 1
T = 2

	HR	MAF
HR	1.000	
MAF	-0.530	1.000

S = 1
G = 2
W = 1
T = 2

	HR	MAF
HR	1.000	
MAF	-0.086	1.000

S = 1
G = 1
W = 2
T = 1

	HR	MAF
HR	1.000	
MAF	0.647	1.000

S = 1
G = 2
W = 2
T = 1

	HR	MAF
HR	1.000	
MAF	0.089	1.000

S = 1
G = 1
W = 2
T = 2

	HR	MAF
HR	1.000	
MAF	-0.415	1.000

S = 1
G = 2
W = 2
T = 2

	HR	MAF
HR	1.000	
MAF	-0.747	1.000

HR by MAF Correlations (Continued)

S = 2
G = 1
W = 1
T = 1

	HR	MAF
HR	1.000	
MAF	.	1.000

S = 2
G = 2
W = 1
T = 1

	HR	MAF
HR	1.000	
MAF	0.583	1.000

S = 2
G = 1
W = 1
T = 2

	HR	MAF
HR	1.000	
MAF	0.350	1.000

S = 2
G = 2
W = 1
T = 2

	HR	MAF
HR	1.000	
MAF	-0.880	1.000

S = 2
G = 1
W = 2
T = 1

	HR	MAF
HR	1.000	
MAF	-0.076	1.000

S = 2
G = 2
W = 2
T = 1

	HR	MAF
HR	1.000	
MAF	0.064	1.000

S = 2
G = 1
W = 2
T = 2

	HR	MAF
HR	1.000	
MAF	0.133	1.000

S = 2
G = 2
W = 2
T = 2

	HR	MAF
HR	1.000	
MAF	-0.577	1.000

HR by MAF Correlations (Continued)

S = 3
G = 1
W = 1
T = 1

	HR	MAF
HR	1.000	
MAF	0.499	1.000

S = 3
G = 2
W = 1
T = 1

	HR	MAF
HR	1.000	
MAF	0.543	1.000

S = 3
G = 1
W = 1
T = 2

	HR	MAF
HR	1.000	
MAF	0.701	1.000

S = 3
G = 2
W = 1
T = 2

	HR	MAF
HR	1.000	
MAF	-0.947	1.000

S = 3
G = 1
W = 2
T = 1

	HR	MAF
HR	1.000	
MAF	0.180	1.000

S = 3
G = 2
W = 2
T = 1

	HR	MAF
HR	1.000	
MAF	-0.274	1.000

S = 3
G = 1
W = 2
T = 2

	HR	MAF
HR	1.000	
MAF	0.501	1.000

S = 3
G = 2
W = 2
T = 2

	HR	MAF
HR	1.000	
MAF	0.130	1.000

APPENDIX F

HR Analysis Data

Tukey Test on Week*Time for HR

Row	W	T
1	1	1
2	1	2
3	2	1
4	2	2

Matrix of Pairwise Comparison Probabilities

	1	2	3	4
1	1.000			
2	0.000 *	1.000		
3	0.326	0.005 *	1.000	
4	0.023 *	0.000 *	0.000 *	1.000

* Significant

Mean HR Values for Week*Time

Row = 1
n = 24
mean = 85.000

Row = 2
n = 24
mean = 92.750

Row = 3
n = 24
mean = 87.542

Row = 4
n = 24
mean = 80.625

Tukey Test on Group*Week*Time for HR

Row	G	W	T
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Matrix of Pairwise Comparison Probabilities

	1	2	3	4	5	6	7	8
1	1.000							
2	0.942	1.000						
3	1.000	0.993	1.000					
4	0.448	0.040 *	0.249	1.000				
5	0.000 *	0.001 *	0.000 *	0.000 *	1.000			
6	0.000 *	0.000 *	0.000 *	0.000 *	0.000 *	1.000		
7	0.000 *	0.000 *	0.000 *	0.000 *	0.448	0.002 *	1.000	
8	0.013 *	0.231	0.036 *	0.000 *	0.423	0.000 *	0.002 *	1.000

* Significant

Mean HR Values for Group*Week*Time

Row = 1
n = 12
mean = 79.000

Row = 2
n = 12
mean = 81.417

Row = 3
n = 12
mean = 79.750

Row = 4
n = 12
mean = 74.667

Row = 5
n = 12
mean = 91.000

Row = 6
n = 12
mean = 104.083

Row = 7
n = 12
mean = 95.333

Row = 8
n = 12
mean = 86.583

APPENDIX G

RPE/HR Relationship Data

Pearson Correlation Matrix for HR and MAF

	RPE	HR	MAF
RPE	1.000		
HR	0.264	1.000	
MAF	-0.259	-0.277	1.000

Individual HR by RPE Correlation Matrices

S = 1
G = 1

	HR	RPE
HR	1.000	
RPE	-0.481	1.000

S = 2
G = 2

	HR	RPE
HR	1.000	
RPE	0.737	1.000

S = 1
G = 2

	HR	RPE
HR	1.000	
RPE	-0.344	1.000

S = 3
G = 1

	HR	RPE
HR	1.000	
RPE	-0.042	1.000

S = 2
G = 1

	HR	RPE
HR	1.000	
RPE	0.125	1.000

S = 3
G = 2

	HR	RPE
HR	1.000	
RPE	-0.582	1.000

Individual HR by RPE Correlations for each Testing Period

S = 1
G = 1
W = 1
T = 1

	HR	RPE
HR	1.000	
RPE	0.000	1.000

S = 1
G = 2
W = 1
T = 1

	HR	RPE
HR	1.000	
RPE	0.017	1.000

S = 1
G = 1
W = 1
T = 2

	HR	RPE
HR	1.000	
RPE	-0.174	1.000

S = 1
G = 2
W = 1
T = 2

	HR	RPE
HR	1.000	
RPE	-0.740	1.000

S = 1
G = 1
W = 2
T = 1

	HR	RPE
HR	1.000	
RPE	.	1.000

S = 1
G = 2
W = 2
T = 1

	HR	RPE
HR	1.000	
RPE	-0.140	1.000

S = 1
G = 1
W = 2
T = 2

	HR	RPE
HR	1.000	
RPE	-0.818	1.000

S = 1
G = 2
W = 2
T = 2

	HR	RPE
HR	1.000	
RPE	-0.720	1.000

HR by RPE Correlation Matrices (Continued)

S = 2
G = 1
W = 1
T = 1

	HR	RPE
HR	1.000	
RPE	0.730	1.000

S = 2
G = 2
W = 1
T = 1

	HR	RPE
HR	1.000	
RPE	0.101	1.000

S = 2
G = 1
W = 1
T = 2

	HR	RPE
HR	1.000	
RPE	.	1.000

S = 2
G = 2
W = 1
T = 2

	HR	RPE
HR	1.000	
RPE	-0.490	1.000

S = 2
G = 1
W = 2
T = 1

	HR	RPE
HR	1.000	
RPE	.	1.000

S = 2
G = 2
W = 2
T = 1

	HR	RPE
HR	1.000	
RPE	-0.475	1.000

S = 2
G = 1
W = 2
T = 2

	HR	RPE
HR	1.000	
RPE	.	1.000

S = 2
G = 2
W = 2
T = 2

	HR	RPE
HR	1.000	
RPE	-0.683	1.000

HR by RPE Correlation Matrices (Continued)

S = 3
G = 1
W = 1
T = 1

	HR	RPE
HR	1.000	
RPE	0.853	1.000

S = 3
G = 2
W = 1
T = 1

	HR	RPE
HR	1.000	
RPE	-0.187	1.000

S = 3
G = 1
W = 1
T = 2

	HR	RPE
HR	1.000	
RPE	-0.101	1.000

S = 3
G = 2
W = 1
T = 2

	HR	RPE
HR	1.000	
RPE	-0.998	1.000

S = 3
G = 1
W = 2
T = 1

	HR	RPE
HR	1.000	
RPE	-0.117	1.000

S = 3
G = 2
W = 2
T = 1

	HR	RPE
HR	1.000	
RPE	0.098	1.000

S = 3
G = 1
W = 2
T = 2

	HR	RPE
HR	1.000	
RPE	0.754	1.000

S = 3
G = 2
W = 2
T = 2

	HR	RPE
HR	1.000	
RPE	.	1.000

APPENDIX H

RPE Analysis Data

Tukey Test on Group*Week for RPE

Row	G	W
1	1	1
2	1	2
3	2	1
4	2	2

Matrix of Pairwise Comparison Probabilities

	1	2	3	4
1	1.000			
2	0.567	1.000		
3	0.000 *	0.003 *	1.000	
4	0.039 *	0.477	0.144	1.000

* Significant

Mean RPE Values for Group*Week

G = 1
n = 24
mean = 11.958

G = 2
n = 24
mean = 12.333

G = 3
n = 24
mean = 13.375

G = 4
n = 24
mean = 12.750

Tukey Test on Group*Time for RPE

Row	G	T
1	1	1
2	1	2
3	2	1
4	2	2

Matrix of Pairwise Comparison Probabilities

	1	2	3	4
1	1.000			
2	0.144	1.000		
3	0.992	0.077	1.000	
4	0.001 *	0.000 *	0.003 *	1.000

* Significant

Mean RPE Values for Group*Time

Row = 1
n = 24
mean = 12.458

Row = 2
n = 24
mean = 11.833

Row = 3
n = 24
mean = 12.542

Row = 4
n = 24
mean = 13.5832

184833

MONTANA STATE UNIVERSITY LIBRARIES
3 1762 10172872 1