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

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.

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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).

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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	5^0 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).

<u>Lower Extremity Research</u>

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.

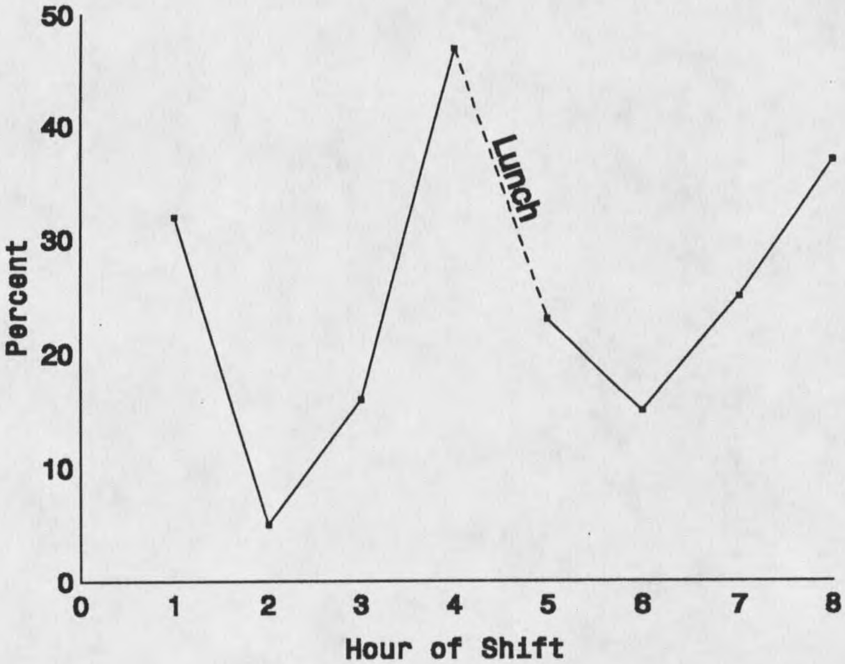

Figure 1. Percent "Most Tired" Among Manual Workers Ages 20 to 35. Source: Griffith et al. (1950)

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.

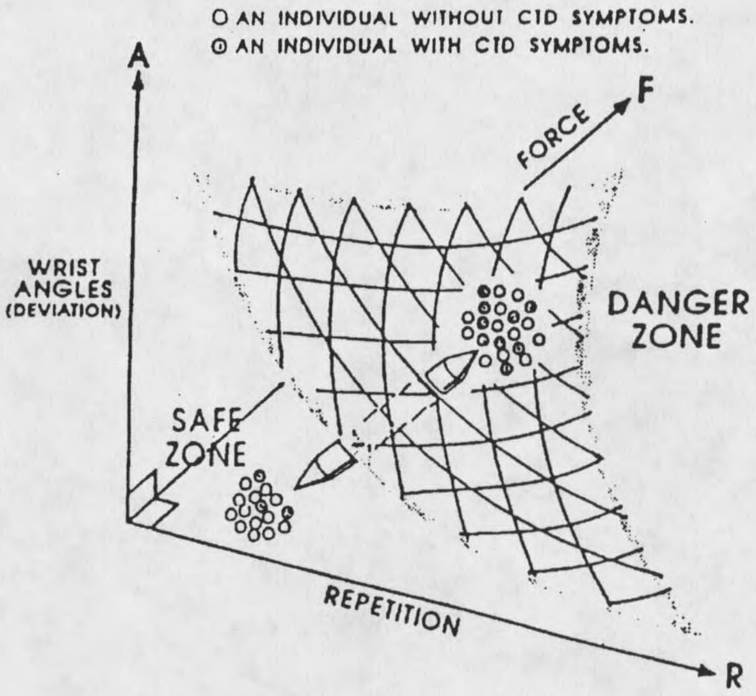

Figure 2. Graphical Representation of Equation 3.
Source: Tanaka and McGlothlin (1993)

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