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누적외상병 예방을 위한 심생리학적 접근법을 이용한 상체작업의 안전한 작업기준의 설정에 관한 연구

Acceptable Work Limits for the Upper Extremities with the Psychophysical Approach

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ABSTRACT

This paper summarizes recent research in the use of the psychophysical method of adjustment to establish acceptable parameters for upper extremity work activities. Results from these studies show that this psychophysical approach can provide reliable guidelines based upon realistic job conditions which involve one or more risk factors for cumulative trauma. It is also shown that this method provides advantages over other psychophysical methods as well as current biomechanical and physiological criteria.

INTRODUCTION

It is widely accepted that cumulative trauma disorders (CTDs) refer to the category of physical conditions resulting from the summation of micro-trauma (Kroemer, 1989) and are generally described chronic, musculoskeletal injuries (Putz-Anderson, 1988). CTDs have been referred to in the literature by a number of different terms varying by discipline and regionality. Some examples include "repetitive strain injury," "repetitive trauma disorders," "repetitive strain disorders," "repetitive motion disorders," "wear and tear disorders," "overuse syndromes,"

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"musculoskeletal disorders," and others(Armstrong, et al., 1986; Salter, 1970; Silverstein,et al., 1986). Within the discipline of ergonomics, the base term "cumulative trauma" has gained some favor since it does not imply a particular etiology based upon one of the recognized risk factors(i.e., repetition).

Occupational risk factors for CTDs has been a source of controversy for some time. Armstrong(1986) stated that during the last 100 years, published articles related to CTDs have been primarily concerned with diagnosis and treatment. However, these articles contain numerous references to work design as a factor in the development of CTDs. The factors consistently immplicated are repetition, force, awkward posture, mechanical stress(caused by contact with work surfaces), vibration, and temperature. Stock(1991) developed strict criteria to evaluate the published literature regarding the relation between work factors and upper extremity tendon and nerve entrapment disorders. She concluded that there is indeed a very strong relation between these disorders and repetitious and force tasks.

Ergonomic Analysis and Control

The control and reduction of work-related CTDs has been traditionally sought through the application of ergonomic principles and proactive medical management. This has included engineering changes to eliminate or reduce risk factors, and/or administrative changes to eliminate or reduce workers' exposure to the risk factors. A confounding dilemma faced by ergonomists is that there are no definitive data concerning what constitutes excessive quantities of risk factors for upper extremity CTD based upon biomechanical or physiological criteria(Kroemer, 1989). Further, there is no definitive data concerning the interaction of risk factors.

Several methods have been suggested to establish criteria for risk assessment. Dury(1987) and Steele, et al.(1990) developed a limiting level of 1000 "damaging wrist motions "(DWM) per hour for hand/wrist work. This level had been extrapolated from Hammer(1934) who had concluded from examining injuries in the tobacco processing industry, early in this century, that human tendons could not tolerate more than 2000 forceful manipulations per hour. Applying the common safety factor of "halves," the modern interpretation provides for the limit of 1000 DWM per hour recommendation. A conceptual model for establishing quantitative guidelines for CTDs which involve multiple risk factors has also been proposed(Tanaka and McGlothlin, 1993). This current paper summarizes recent work to apply the psychophysical methodology to establish acceptable parameters for upper extremity work.

THE PSYCHOPHYSICAL APPROACH

Classical Methods

The study of psychophysics can be referred to as one of the original "schools" of psychology originating in the 1850's when scientists considered the relation between human sensation and physical stimuli(Stevens, 1975). Central to these early investigations was the development of a method of measurement which could describe how sensations differ in both quality and magnitude. For example, vision, hearing, or tactile sensations all rely upon different modalities which vary in degree from acute to dull, loud to soft, etc.. In general, the principles that govern sensory reaction to stimuli are the "more than," "different from," or "same as" principles. By the mid-20th century, due in large part to the work of S.S. Stevens, the modeling technique which gained greatest acceptance was the psychophysical power law(often referred to as the Stevens Power Law). According to Stevens(1975), nature has favored using the power law because power functions are common throughout the sciences. The psychophysical power law is stated as follows:

$$S = kI^n$$

where, S = Magnitude of human sensation
k = Constant that depends upon unit of measure for physical stimulus
I = Intensity of physical stimulus
n = Exponent experimentally de termined for each sensory continuum

Gescheider(1984) outlined four basic methods or protocols used in the modern "psychophysical approach" which use fundamentally different criteria and usually have different objectives. A misunderstanding of these methods, with their strengths and weaknesses, are often at the heart of criticisms levied against psychophysics. The *method of constant stimuli* is a protocol aimed at determining either absolute thresholds, difference thresholds, or points of subjective equality between stimuli. This method receives its name due to the constant number and equidistant, discrete stimulus intensity levels presented to the subject. The *method of limits* also seeks to determine thresholds or points of subjective equality. However, in this method, the stimulus is presented to the subject in continuous, ascending or descending levels of intensity. This method is familiar to many as the method used to determine hearing thresholds. The *method of adjustments* is fundamentally different in that the subject, rather than the experimenter, have control and make adjustments in the stimulus intensity level in order to match a predetermined criteria. It is the method of adjustment which has been used successfully in manual lifting experiments to determine an acceptable weight of lift(Snook,1985). In these experiments, subject are asked to adjust the stimulus(lifting load) in order to reach a maximum level of intensity which would not result in undue stress or overexertion. The *method of ratio scaling* seeks to derive a relationship between subjective characteristics and a numeric scale. There are four common protocols of ratio scaling: 1) ratio production; 2) ratio estimation; 3) magnitude production; and 4) magnitude estimation. The "production" protocols ask the subject to produce or recreate a stimulus intensity level based upon a numerical value associated with the continuum. Requesting a subject to produce half of their maximum grip force(without feedback) would be an example of ratio production. The "estimation" protocols require the subject to provide a numeric value which represents a particular stimulus intensity level. Arguably the most widely known form of an estimation protocol is the Rating of Perceived Exertion(RPE) scale(Borg, 1970) and its many derivatives.

Psychophysics in Upper Extremity Work

Marley(1990) adapted a psychophysical adjustment protocol for use in establishing maximum acceptable frequency(MAF) for a sheet metal drilling activity which required various wrist postures. This protocol has been described extensively elsewhere and results have been found to be reliable (Fernandez, et al., 1993; Marley and Fernandez, in press). Kim and Fernandez (1993) extended this protocol to include the additional task factor of applied force and Viswanath and Fernandez(1992) and Davis and Fernandez(in press) have investigated other postural combinations and gender effects. The results of these studies have demonstrated that wrist flexion significantly reduces MAF and that males select significantly greater values than females. In addition, as required force increases, MAF decreases significantly. Willis(1994) observed drilling during 16 different psychophysical bouts. His results showed that MAF selected after an initial 25 minute bout did not differ significantly from the value following the 4th consecutive bout(over a 2 hour period with frequency randomly set at the beginning of each bout). In addition, he found no significant circadian effect nor significant differences between consecutive testing days, but there was up to 12% variability in MAF between periods of 7 to 10 days on non-drilling activity. Table 1 summarizes the current MAF guideline.

In addition to these studies, researchers have conducted psychophysically adjusted frequency experiments in grasping and pinching tasks(Dahalan and Fernandez, 1993; Klein, 1994). Results indicate that MAF reduced exponentially when required

Table 1. MAF per minute at various wrist postures.

Wrist Posture	Degree Deviation	Males			Females		
		Mean	STD	N	Mean	STD	N
Neutral	0	14.15	2.92	21	12.1	2.7	39
Flexion	10	13.0	2.92	15	10.5	2.26	27
	20	11.9	2.45	15	9.3	1.84	27
	25	-	-	-	9.4	2.63	12
	30	10.4	2.38	15	-	-	-
	40	8.9	1.75	15	-	-	-
	50	-	-	-	8.22	3.22	12
Extension	20	-	-	-	11.5	3.31	15
	40	-	-	-	10.9	2.29	15
Ulhar Deviation	15	-	-	-	11.3	2.36	12
	20	-	-	-	12.2	3.45	12
	30	-	-	-	10.4	2.72	12
	40	-	-	-	12.9	3.95	12
Radial Deviation	10	-	-	-	11.7	3.19	12
	20	-	-	-	11.1	3.46	12

[Adapted from Marley and Fernandez(in press); Davis and Fernandez(in press); Willis 1994); Kim and Fernandez(1993); Viswanath and Fernandez(1992)] force and duration were increased(recall the Power Law). Abu-Ali, et al.(1994) recently reported the use of the psychophysical adjustment method to establish work cycle parameters for repetitive grasping. They found that subjects selected greater rest periods, proportional to exertion periods, when required force and wrist deviation were increased. Some of these findings are summarized in Figures 1 and 2.

CONCLUDING REMARKS

Ergonomists seek to eliminate or reduce the presence of work-related CTD risk factors. Beyond technical and economic considerations, the acceptable level(s) of one or more combined risk factors are often unknown, further complicating the design process. In the absence of objective biomechancial or physiological criteria, the psychophysical approach may be utilized to elicit acceptable task parameters for the upper extremities. Specifically, the research summarized in this paper are based upon the psychophysical method of adjustment, which may be the most appropriate to establish realistic and reliable guidelines for upper extremity tasks since it seeks to establish a specific intensity threshold(e.g., frequency, force, duration, etc.), thus allowing work designer to address particular production needs involving exposure to CTD related job factors.

It is unclear if other psychophysical methods will prove as useful in this regard, particularly ratio scaling(such as in the form of exertion scales). While these scales are certainly useful in performing inter or intra-task comparisons of job factors, they cannot be utilized to establish specific design parameters. Future studies will examine a broader set of tasks with various combinations of risk factors. Epidemiological studies should examine the psychophysically determined risk levels versus morbidity.

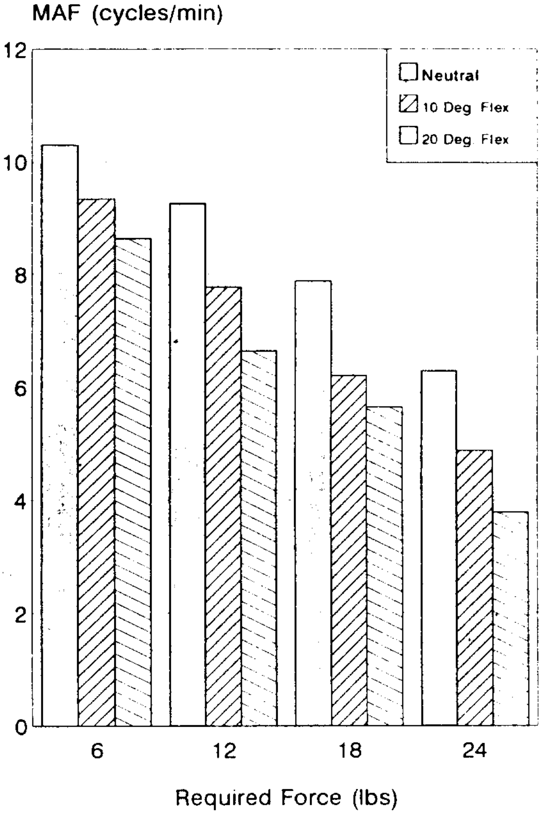

Figure 1. MAF per minute at various applied force and levels.

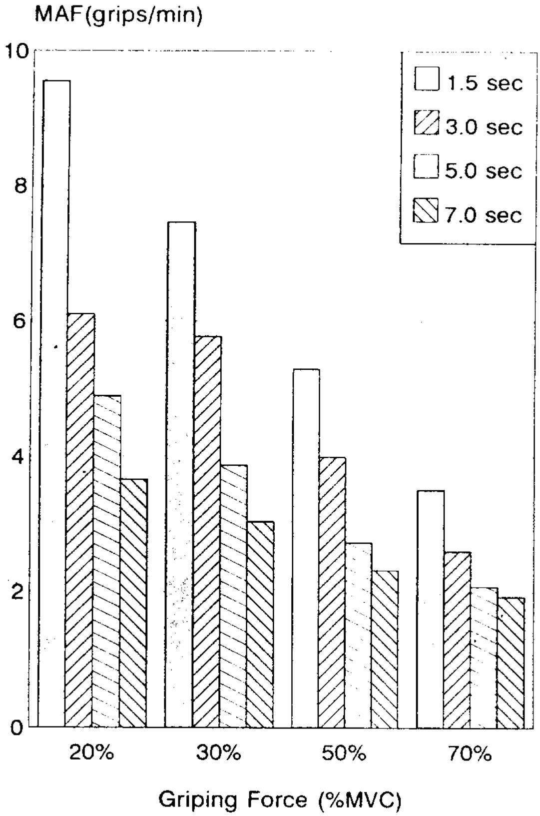

Figure 2. Effect of required force and duration on MAF per minute for grasping.

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