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The development and application of psychophysical methods in upper-extremity work tasks and task elements

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ABSTRACT

This paper examines an approach to modeling the relationship between perceived acceptable work exposures and physical stressors in upper-extremity tasks using psychophysical methods. Several years of laboratory-based studies and results from a variety of simulated work tasks and task elements are summarized. The original impetus of these studies was founded in the pioneering work and successful application of psychophysical methods applied to manual materials handling tasks (e.g., lifting) generally beginning in the 1960s and 1970s. This approach provided unique and feasible solutions to work design problems involving exposure to the hazard of cumulative trauma. Presently, these methods were adapted to studying common upper-extremity tasks and task elements. Results provide conclusive evidence of the impact of required posture, force, gender and other variables on acceptable task frequency. These results and the psychophysical method in general, may be particularly helpful in establishing realistic and reasonable work design guidelines when workers are exposed to multiple, simultaneous hazards such as force, frequency, with deviated posture, etc, and in the absence of well-defined biomechanical or physiological-based models. Finally, a review of psychophysical theory and methods which can be applied to a wide range of occupational activities is provided.

Relevance to industry: Psychophysical methods have been utilized for realistic work design guidelines for jobs with risk of musculoskeletal disorders, particularly the low back. This paper summarizes psychophysical methods and results developed for upper-extremity tasks. Required task frequencies should be reduced when postural deviation, required force, and other factors such as vibration, are greater than nominal.

1. Introduction

During the latter half of the last century, a number of investigators in occupational safety began to employ psychophysical methodologies to help understand and predict human performance in heavy physical labor. These methods gained favor with ergonomists and other occupational safety professionals as a reliable and valid approach to set reasonable work design limits for jobs containing risk of musculoskeletal disorders (MSDs), particularly in the absence of a well-defined biomechanical or physiological model. These limits were applied generally to “heavy” physical work such as lifting in manual material handling activities.

Several investigators pioneered the use of psychophysics in the realm of low back injury risk in manual material handling and related tasks (Ayoub, 1987; Ayoub et al., 1980; Snook and Ciriello, 1974; Snook and Irvine, 1967; Snook et al., 1978; Snook, 1978; Snook, 1985a,b). As mentioned above, the psychophysical approach tended to be useful in the absence of biomechanical and/or physiological based models. This is particularly true when multiple risk factors for MSDs may be present for a particular task and no realistic way to assess risk for an individual factor, much less multiple factors.

Beginning in the 1980’s, attention in the occupational safety community began focusing on upper-extremity tasks which appeared to be related to the development of other forms of MSDs. Carpal Tunnel Syndrome and Tenosynovitis related to work factors are common examples of these other forms. Scientists at the U.S. National Institute for Occupational Safety and Health (NIOSH) proposed research initiatives and otherwise sought medical and ergonomic solutions to these classes of MSDs.

Our group began to explore the extension of psychophysical methods for work design in those tasks involving primarily the upper-extremities, as opposed to the low back or whole-body.

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Specific methods for examining upper-extremity work tasks using psychophysics had not been widely developed at that time. The bulk of this paper summarizes the outcomes of this body of research conducted in the ergonomics laboratory at Wichita State University in the late 1980's and 90's. But first, the science of psychophysics as applied to general work activities will be explored, and then related to upper-extremity tasks.

2. The science of psychophysics

Psychophysics is concerned with human sensations associated with external physical stimuli. The study of psychophysics can be referred to as one of the original "schools" of psychology originating with Gustav Fechner's work in the mid-1800s (Watson, 1978). Central to these early investigations was the development of measurement protocols that could describe how sensations differ in both quality and magnitude. For example, vision, hearing or tactile sensations all rely upon different modalities that vary in degree from "acute to dull," "loud to soft," and "light to heavy". Each of the sensory modalities also introduces a unique bias in that none is linear across all stimulus intensity levels and each modality has a unique form of non-linearity.

In general, the descriptive principles that govern sensory reaction to stimuli are measured using the "more than," "different than," or "same as" techniques. By the mid-20th century, due in large part to the work of S.S. Stevens, the modeling technique that had gained the greatest acceptance was the psychophysical power law, sometimes referred to as the Stevens Power Law, though it was an adaptation of Fechner's equation. According to Stevens (1975), nature has favored using the power law because similar functions are common throughout the sciences. The psychophysical power law is stated in the following relationship:

$$S = kI^n$$

where,

S = sensory magnitude
k = constant, dependent upon unit of measurement of stimulus
I = intensity of physical stimulus
n = exponent that is experimentally determined for each sensory continuum.

By examination of the power law, one can see that the exponent (n) defines a non-linear relationship between a given physical stimulus and its corresponding sensation. Table 1 provides a summary of several values of n determined through experimentation. Note the values for these exponents and consider $n = 0.67$ for loudness as an example. This indicates that as the actual sound energy level increases, the human perceiver will detect the increase, but at a proportionally lower rate for each energy unit of sound. Likewise, consider muscular exertion. According to this exponent value ($n = 1.7$), as the level of muscular exertion increases, the perceived effort will increase disproportionately. For example, if the weight of an object being handled doubles, then the perceived muscular exertion to handle this weight will be more than doubled.

Table 1
Examples of power law exponents (adapted from Stevens 1975).

Stimuli	Condition	Exponent (n)
Loudness	dB @ 3 kHz	0.67
Taste	Salt	1.40
Taste	Sucrose	1.30
Cold	Metal contact on arm	1.00
Warmth	Metal contact on arm	1.60
Muscle force	Static exertion	1.70
Heaviness	Lifting objects	1.45
Electric shock	Current through fingers	3.50

2.1. Psychophysics and ergonomics

The typical objective of ergonomic studies utilizing the psychophysical approach is to empirically quantify subjective tolerance to occupational stress. One of the major dependent variables developed using the psychophysical approach is known as the "acceptable" limit(s) of work referring to the perceived level of discomfort and/or fatigue acceptable under given working conditions and objective criteria (Ayoub and Dempsey, 1999). This is as contrasted to the concept of a "maximum" tissue tolerance or capacity normally sought using biomechanical or physiological methods, when applicable. Thus, most working limits that contain the term "acceptable" have been derived using one of the methods of the psychophysical approach.

As described above, within the domain of ergonomics, the goal of the psychophysical approach is to quantify subjectively-determined, or individually perceived, tolerance to occupational stressors. As such, psychophysical methods provide the ergonomist with a powerful yet flexible set of tools to help establish reasonable work limits in the absence of a well-defined biomechanical or physiological model. One important value of psychophysical modeling is realized in the ability to establish reasonable guidelines in the absence of known limits derived from other approaches such as from epidemiology or biomechanics. Furthermore, many tasks involve the presence of multiple risk factors for work-related musculoskeletal disorders (e.g., excessive force with awkward postures). An existing method for determining a "safe" level of work is not clear from other approaches in such situations which are generally based upon exposure to singular risk factors.

Thus, psychophysics offers an opportunity to examine worker perception of tasks involving multiple occupational stressors by allowing the worker to "integrate" this information. In the psychophysical approach, the human serves as our instrument of observation. Like any instrument, the human observer can be biased and lead to inaccurate measures. Nevertheless, human perception can be a reliable means of measurement. The key to the successful implementation of a psychophysical approach is to then provide realistic objective criteria to the worker (our human participant). This will be discussed in more detail in the following sections.

2.2. Psychophysical methods

The following section outlines several of the key methodologies used in psychophysics, particularly as it relates to occupational ergonomic design and analysis. Each methodology has an associated protocol for establishing the desired parameters. The reader will note that throughout this section that the terms "threshold" and "limit" are used frequently. In some practices these terms are used synonymously, but there is a subtle yet significant difference for which one should be cognizant.

The term "threshold" is meant to convey a measurable level of stimulus intensity at which the human participant can detect the stimulus. A common example is the minimum (or absolute) threshold below which a stimulus cannot be detected and above which it will be detected. Another type of threshold is known as the "difference threshold" where there may be measured a range of stimulus intensity levels within which the human participant cannot perceive a difference. Consequently, levels of intensity within the range of a difference threshold are sometimes referred