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by Stover H Snook, PhD[1]

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Psychophysics is a very old branch of psychology that is concerned with the relationship between physical stimuli that occur in the "outside world", and the sensations they produce in the body's "inside world". According to modern psychophysical theory, the strength of a sensation is directly related to the intensity of its physical stimulus by means of a power function. The history and development of psychophysics is briefly reviewed, and the application of psychophysics to manual handling tasks and repetitive hand and wrist motion is described. The advantages and disadvantages of psychophysics are discussed. The following 4 directions for future research are suggested: further validation of the data, expansion into other areas of concern (eg, other body parts, jobs, and postures), broadening of the subject base by including symptomatic subjects, and greater inclusion of psychophysical measures (eg, pain, fatigue, and discomfort) in studies of musculoskeletal disorders.

Key terms cumulative trauma, lifting, low-back pain, manual handling, repetitive motion.

In recent years, psychophysics has played a prominent role in the development of ergonomic guidelines. For example, psychophysics was one of the approaches used to define the components of the lifting equation developed by the National Institute for Occupational Safety and Health (NIOSH) in the United States.(1) In discussing the future directions of psychophysical studies, it is useful to see where psychophysics has been and what effect it has had as a research methodology. This paper first discusses the history of psychophysics and its application to musculoskeletal disorders. Next, an objective critique of psychophysics is presented, citing its advantages and disadvantages. Finally, several suggestions are offered on where psychophysics could go from here.

History of psychophysics

Psychophysics is a very old branch of psychology that is concerned with the relationship between physical stimuli that occur in the "outside world" and the sensations they produce in the body's "inside world". It began 165 years ago with the investigations of Ernst Heinrich Weber (1795—1878), a professor of anatomy (and of physiology) at the University of Leipzig in the early 1800s (2, 3).

Weber was very interested in the sense of touch. In 1834 he ran some experiments on the perception of weight and found that weight must be increased by a constant fraction of its value to be just noticeably different (JND). This constant fraction is about 1/40, and it is independent of the magnitude of the weight. In other words, if there is a 40-gram weight in one hand, there must be a 41-gram weight in the other hand before a difference is noticed between the 2 weights. If there is an 80-gram weight in one hand, there must be an 82-gram weight in the other before a difference is noticed. This became known as Weber's Law,

delta I/I = constant,

where I is the weight (intensity) and delta I is the increment that the weight must be increased to be just noticeably different.

Another professor at the University of Leipzig became very interested in Weber's research. Gustav Theodor Fechner (1801—1887) was a professor of physics and active in studying the relationship between body and mind (2, 3). Fechner expanded upon Weber's work and, in 1860, published a book called *Elemente der Psychophysik*, in which he proposed what is now known as Fechner's Law. This law states that the strength of a sensation (S) is directly related to the intensity of its physical stimulus (I) by means of a logarithmic function

1 Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, United States.

Reprint requests to: Dr Stover H Snook, 10472 SE Amberjack Court, Hobe Sound, Florida 33455, USA. [E-mail: stover@ecqual.net]

($S = k \log I$). The constant k is a function of the particular unit of measurement used.

Fechner's Law was known to be accurate in the middle ranges of stimuli and sensations, but not so accurate at the extremes. In 1950 SS Stevens, a professor of psychology at Harvard University, proposed that the relationship between stimuli and sensations was not a logarithmic one, but a power function ($S = kI^n$)(4). Stevens and his colleagues collected data to show that the power function was accurate throughout the entire range of stimuli and sensations.

When plotted in log-log coordinates, a power function is represented by a straight line, with the exponent (n) being equal to the slope of the line. Over the years, exponents have been experimentally determined for many types of stimuli. For example, 3.5 is the exponent for electric shock, 1.3 for taste (salt), and 0.6 for loudness (binaural). Of particular interest in this paper is the perception of muscular effort and force, both of which have been found to obey the power law, and both with an exponent of approximately 1.6 (5, 6).

Application of psychophysics

Psychophysics has been applied to practical problems in many areas. For example, psychophysics has been used to develop the scales of loudness (decibel scale), effective temperature (EF scale), and brightness (bril scale) (4, 7, 8).

Psychophysics was used by Borg in developing his ratings of perceived exertion (RPE) (5, 9), and by Caldwell and his associates in the development of effort scales (10, 11). The first applications of psychophysics to manual handling tasks were 2 United States Air Force studies of lifting. The Air Force studies used young, male college students to investigate the loading of ammunition cases into F-86H aircraft, as well as other operational and maintenance activities. Unfortunately, the researchers did not control for repetition rate, training, or fitness, nor did they mention or discuss the concept of psychophysics (12, 13).

About 30 years ago, the Liberty Mutual Research Center began to apply psychophysics to manual handling tasks, expanding upon the earlier Air Force studies (14). The purpose was to develop recommendations for use in reducing industrial low-back compensation claims. At that time, psychophysics was the only method that could yield usable data for evaluating manual handling tasks. In the Liberty Mutual studies, the worker was given control of 1 of the task variables, usually the weight of the object being handled (15, 16). All the other variables, such as repetition rate, size, height, distance, were controlled. The worker then monitored his or her own feelings of exertion or fatigue and adjusted the weight of the object accordingly. It was believed that only the individual worker could sense the various strain associated with manual handling tasks and only the individual worker could integrate the sensory inputs into one meaningful response. Indeed, there is now some evidence that a person incorporates physiological and biomechanical stresses when making psychophysical judgments (17, 18).

Since the early Liberty Mutual studies, numerous researchers have used psychophysical methodology to study manual handling tasks. Ayoub & Dempsey (19) have recently reviewed much of this research. Other researchers have compared the psychophysical approach with other approaches to manual handling tasks (viz, biomechanical, physiological, and intraabdominal pressure) (19—21). In addition to manual handling tasks, psychophysics has also been utilized in the investigation of repetitive hand and wrist motion (22—33) and the design of stairways (34), chairs (35), and workstations with video display terminals (36). (The latter 2 studies used preferred settings as the dependent variable, although the authors did not specifically identify the technique as psychophysics.)

The development of comprehensive manual handling guidelines or design data bases have resulted from psychophysical studies (1, 15, 16, 37, 38). Several studies have investigated the effectiveness of these guidelines in reducing low-back disorders in industry (39—42). Other studies have found that, when workers are asked to rate subjectively the degree of physical effort or strain in their jobs, low-back pain appears significantly more frequently among those who believe their work to be harder (43, 44).

Critique of psychophysics

Every methodology has its advantages and disadvantages, and psychophysics is no exception. The major advantages and disadvantages of psychophysics were first reviewed by Snook in 1985 (45) and consisted of the following:

1. Psychophysics permits the realistic simulation of industrial work. For example, lifting can be a dynamic task through a given distance, and not just an isometric pull. Task frequency can be varied from very fast rates to very slow rates.

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. Psychophysical results are consistent with the industrial engineering concept of a "fair day's work for a fair day's pay" [eg, the standard task of walking at 3 miles

(4.8 km) per hour]. With the exception of very fast frequency tasks, psychophysical results are consistent with metabolic criteria of continuous or occupational work capacity.

4. Psychophysical results are very reproducible.

5. Psychophysical results appear to be related to low-back pain. Several investigators have found that, when workers are asked to rate subjectively the degree of physical effort or strain in their jobs, low-back pain appeared significantly more frequently among those who believed their work to be harder.

In a recent review of psychophysics, Ayoub & Dempsey (19) expanded the list with the following additional advantages:

6. Currently, there is a considerable amount of psychophysical data for manual materials handling available that was collected from industrial workers. Many physiological models are based upon data collected from university students. Similarly, cadaver data used to set spinal compression limits are of questionable value.

7. Psychophysical judgments take into account the whole job and integrate biomechanical and physiological factors (17, 18).

8. Psychophysical data can be applied to a wider array of tasks than either the biomechanical or physiological approach.

9. For manual materials handling that must be performed under postural restrictions (ie, maintenance work and mining), psychophysics can be used to develop handling limits specific to the tasks being examined.

10. The psychophysical approach is less costly and time consuming to apply in industry than many of the biomechanical and physiological techniques.

There is one additional advantage of psychophysics which became obvious during experimentation with repetitive motion tasks at the Liberty Mutual Research Center.

11. Psychophysics is particularly useful in exposing subjects to hazardous tasks without excessive risk. Allowing subjects to control 1 of the variables reduces the risk of overload; it also increases the probability of approval from institutional review (human use) committees.

The major disadvantages of psychophysics cited by Snook in 1985 consisted of the following:

1. Psychophysics is a subjective method that relies on self-report from subjects. It will probably be replaced when and if more objective methods become available. [In the opinion of Ayoub & Dempsey, the methods available in 1998 are not much more objective than the methods available in 1985 (19).]

2. Psychophysical values from very fast frequency tasks are higher than recommended metabolic criteria. Permissible loads for very fast tasks should probably be based upon metabolic criteria.

3. Psychophysics does not appear sensitive to the bending and twisting motions that are often associated with the onset of low-back pain. For example, psychophysical values are higher for the floor-to-knuckle height lift than for the knuckle height to shoulder height lift. It is true that stronger back and leg muscles are used when a subject lifts from the floor, but it is also true that this particular bending motion is associated with almost half of the compensable cases of low-back pain.

Ayoub & Dempsey (19) cite 2 additional disadvantages of psychophysics in their review:

4. The assumption that the subjective work loads selected by subjects are below the threshold for injury has not been validated. This is the most important limitation.

5. Some psychophysical values may violate biomechanical criteria (although there is not complete consensus regarding biomechanical criteria).

Future directions of psychophysics

Where should psychophysics go from here? Considering the advantages and disadvantages of psychophysics, 4 directions for future research are suggested.

The 1st direction is for further validation of the data. Several investigators have suggested that the primary research need is for epidemiologic field verification of psychophysical data (19, 20, 46, 47). Do the recommended values actually lead to a reduction in musculoskeletal disorders? Verification is a common need for all approaches to manual handling task evaluation. Limited psychophysical verification data for manual handling tasks have been reported by Snook et al (39), Liles et al (40), and Herrin et al (41). However, further research would provide more quantitative support. There have been no psychophysical verification data reported for repetitive motion tasks.

The 2nd future direction is an expansion of psychophysical research to new areas of concern. Past psychophysical studies have investigated a limited number of manual handling and repetitive motion tasks. The primary emphasis has been on the lower back and the upper extremities. Future studies could be directed towards other body parts such as elbows, shoulders, knees, and the neck. Other types of jobs and postures could also be investigated, as well as combinations of jobs and postures. Psychophysics can also be used to evaluate equipment design such as chairs, desks, tools, and production equipment. Modeling individual psychophysical capacity to indicate risk potential and determining recommendations for more than 8 hours of work have also been suggested (19).

The 3rd future direction calls for a broadening of the subject base by including symptomatic subjects. Past research on maximum acceptable weights and forces has been conducted with asymptomatic subjects. It is important to recognize that, currently, we cannot prevent all musculoskeletal disorders from occurring and that many people continue to work with pain. However, we can prevent much of the disability that results if we begin to design jobs for people with disorders, as well as for people without disorders. Future psychophysical studies should utilize subjects with various musculoskeletal disorders in an effort to develop design criteria for jobs that will enable people to remain working, or return to work sooner. As discussed in the critique, psychophysics appears to be insensitive to bending and twisting in asymptomatic subjects, but it may be sensitive to bending and twisting in subjects with low-back pain. Several investigators have used psychophysical approaches to assess patients in a rehabilitation setting (48—52). However, the capabilities and limitations for symptomatic workers have yet to be determined.

The 4th future direction is for the greater inclusion of psychophysical measures in studies of musculoskeletal disorders. Pain, fatigue, and discomfort are important dependent variables (outcome measures) for musculoskeletal studies. However, these are subjective variables that are difficult to measure. Correlates of pain, fatigue, and discomfort (eg, strength, duration, heart rate, body temperature, lost time) can be objectively measured, but the variables themselves must rely on subjective measures such as psychophysics. In this case, the subjective nature of psychophysics is an advantage, not a disadvantage. Future musculoskeletal studies should incorporate psychophysical measures of pain, fatigue, and discomfort, in addition to measures of bodily function, task performance, and disability. The development of symptom surveys represents a good beginning (53—56), especially those that scale pain or discomfort (57—59). Other recent examples include a psychophysical rating of ergonomic stressors in a study of upper-extremity disorders (60) and a psychophysical measure of pain intensity in an intervention study of low-back pain (61).

Concluding remarks

A primary goal of researchers attending PREMUS is to reduce musculoskeletal disorders. One of the ways in which such a reduction is attempted is through ergonomics (ie, designing the job to fit the capabilities and limitations of as many workers as possible). The 1st step in ergonomics is to evaluate the job; the 2nd step, if necessary, is to redesign the job. If a well-designed job does not reduce musculoskeletal pain, it should certainly reduce the disability. A well-designed job will help the worker cope with the pain and remain on the job. There is considerable evidence that remaining active and on the job is excellent therapy (62—66).

Psychophysics is a particularly useful and versatile tool for evaluating jobs, the 1st step in ergonomics. Psychophysics is best used in conjunction with biomechanical, physiological, and epidemiologic methods – for the purpose of designing jobs and assessing patients. In the words of Nortin Hadler (67), one of the strongest critics of ergonomics, "we should provide workplaces that are comfortable when we are well, and accommodating when we are ill" [p 939]. By my definition, that *is* ergonomics, and that should be the goal.

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