Physical Strength Assessment in Ergonomics

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1. Introduction

Humankind's interest in measurement of human physical strength probably dates to the first humans. At that time, life was truly a struggle in which the fittest survived. To a great extent, fittest meant strongest. Interestingly, current interest in human physical strength in the workplace stems from 1970–1980s vintage research demonstrating that persons with adequate physical strength are less likely to be injured on physically demanding jobs. Survival in many modern workplaces may still be a case of survival of the strongest.

There is, however, a flip side to this issue — that persons with limited strength are more likely to be injured on "hard" jobs. To address this problem, we can apply what we know about physical strength to job design. "Hard" jobs can be redesigned to be within the physical strength capability of most people. Since physical strength is important to these jobs, we must find ways to quantify it through testing.

This publication concerns human physical strength testing. Its purpose is not to recommend any particular type of testing, but rather to describe the types of testing available and their uses. It is up to each individual user of strength testing to decide which testing technique is most appropriate for his or her particular application. This booklet discusses four types of strength testing: isometric, isoinertial, psychophysical, and isokinetic.

Human Strength

Before describing the different types of strength measurement, we must define the term "strength" and explain the concept of strength measurement. *Strength* is defined as the capacity to produce force or torque with voluntary muscle contraction. *Maximum strength* is defined as the capacity to produce force or torque with a maximum voluntary muscle contraction.(1,2) These definitions include some key words that must be explained.

A voluntary muscle contraction is "voluntary." When a person's physical strength is measured, only the effort the person willingly puts forth at the time is measured. Thus, when we test a person's "maximum strength," we are not measuring his or her actual maximum, but some lesser value representing what he or she is comfortable expressing at the time with the existing equipment and environmental conditions. Interestingly, when researchers startled persons being tested (e.g., by setting off a starter's pistol behind them), they have found significant increases in measured strength.(3) It has been hypothesized that the lower strength displayed during normal testing provides a margin of safety against overloading and damaging muscle tissue. The test equipment and the tested person's familiarity with the process also influence the "voluntary" strength output. The interface between the tested person and the test equipment is particularly important. A poorly designed interface induces localized tissue pressures that vary from uncomfortable to painful. In this situation, testers are measuring voluntary discomfort tolerance — not strength. It is important for strength researchers to keep the "voluntary" nature of their data in mind when they are designing their equipment and protocols.

The definition of strength also involves force or torque. Strength researchers and users of strength data must understand this distinction. We commonly use the terms "muscle force" and "muscle strength" to describe the strength phenomenon. Technically, this is incorrect. In most human movements and force exertions, a group of individual muscles (a functional muscle group) actually works together to produce the observable output. In complicated exertions, a number of functional muscle groups work together to produce the measured output. Elbow flexion strength, for example, is the result of the combined efforts of the biceps brachii, brachialis, and brachioradialis; and a squat lift is the result of the combined efforts of the legs, back, and arms. In elbow flexion, each individual muscle's contribution to the functional muscle group's output depends on the posture of the arm when being tested. Thus, when we measure elbow flexion strength, we are measuring the strength of the elbow flexor muscle group, not the strength of any individual muscle.

Furthermore, we are measuring (recording) the force created by the functional muscle group(s) against the interface between the person and the equipment (a set of handles, for example). Consider the elbow flexion measurement depicted in Figure 1. The force generated by the elbow flexor muscle group is shown by F_m. This force acts through lever arm "a." In so doing, it creates a torque about the elbow joint equal to F_m x a. The measured force (*Q, R*, or *S*) depends on how far (*b, c,* or *d*) the interface (force cuff) is from the elbow. Assuming that the exertion is static (nothing moves) in this example, the measured force (on the

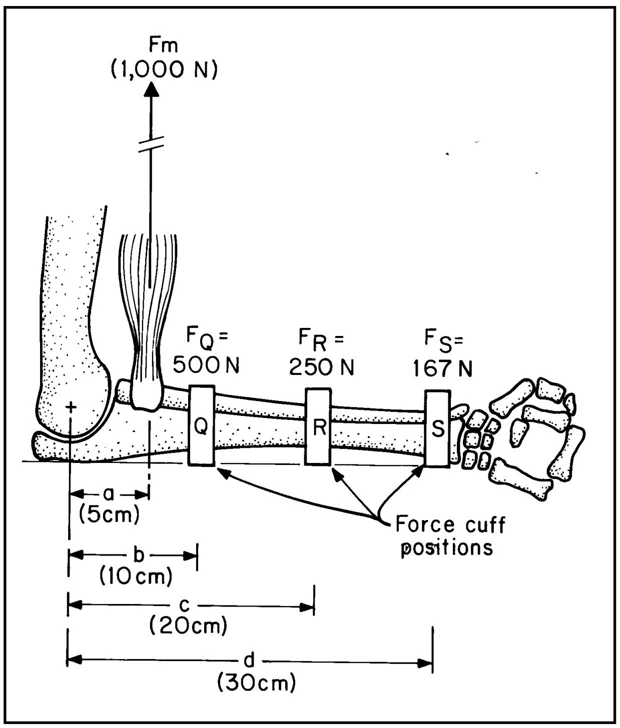

Figure 1—
Given a constant muscle force (F_m), forces measured at various distances from the elbow will result in different force readings (F_Q, F_R, or F_S).

gauge) will equal the elbow flexor torque divided by the distance that the gauge's associated force cuff is from the elbow joint. That is,

$$Q = (F_m \text{ x } a)/b \quad (1)$$

or

$$R = (F_m \text{ x } a)/c \quad (2)$$

or

$$S = (F_m \text{ x } a)/d \quad (3)$$

As we move the interface (force cuff) from the elbow to the hand, the measured force will decrease. This example highlights four points. First, as Kroemer et al. wrote in the *International Journal of Industrial Ergonomics,* "muscular strength is what is measured by an instrument."[4] Second, people publishing or using strength data must report or understand in detail how the measurements were done. Third, the differences in published strengths of the various body parts may be due to differences in the measurement methods and locations. Fourth, interface locations selected using anthropometric criteria will result in more consistent results across the population measured.[5]

In summary, a record of a person's strength describes what the instrumentation measured when the person voluntarily produced a muscle contraction under a specific set of circumstances with a specific interface and instrumentation.

Purposes of Strength Measurement in Ergonomics

People may want to collect human strength data for a number of reasons. One common reason is to build an anthropometric database of population strength data that can be used to create design data for products, tasks, equipment, and so forth, as well as for basic research into the strength phenomenon. This publication focuses on two common uses of physical strength assessment in ergonomics: *worker selection and placement* and *job design*.

Worker Selection and Placement

Worker selection and placement programs ensure that jobs involving heavy physical demands are not performed by those who lack the necessary strength capabilities.[6] It should be noted that this method is not the preferred strategy of the ergonomist; it is a provisional measure for controlling work-related musculoskeletal disorders (WMSDs) when job design cannot be used to alleviate task demands. Nonetheless, this method can be effective in reducing the harmful physical effects caused by the mismatch of worker and job, *given adherence to two fundamental principles*: ensuring that (1) the strength measures closely simulate the actual high-strength elements in a job and (2) strength assessment is performed only under circumstances where those who may be at risk of WMSD can be predicted. The following paragraphs describe these issues in more detail.

It has become quite clear over the past several years that strength, in and of itself, is a poor predictor of the risk of future injury to a worker.[7-9] A worker's strength capacity predicts risk of injury only when it is carefully equated with job demands.[10] All too often, collecting data on individual workers' strength is emphasized, while evaluation of actual job demands receives little or no attention. Recent evidence shows that job demands cannot be generalized as "light" versus "heavy";[11] a careful biomechanical evaluation of strenuous tasks performed by the worker needs to be done.

The following scenario illustrates the need to analyze strength in relation to specific job demands: An employer has an opening for a worker in a physically demanding job and wishes to hire an individual with strength sufficient for the task. This employer decides to base his employment decision on a strength test given to a group of applicants. Naturally, he selects the applicant with the highest strength score to perform the job. The employer may have hired the strongest job applicant; however, he may not have decreased the risk of injury to his employee if the demands of the job still exceed this individual's maximum voluntary strength capacity. This example should make it clear that only through knowing both the person's capabilities *and* the job demands can worker selection protect workers from WMSDs.

The second issue to be considered when implementing worker selection is the test's *predictive value*. The predictive value is a measure of the test's ability to determine who is at risk of future WMSD.[6] In the case of job-related strength testing, the predictive value appears to hold *only* when individuals are tested for jobs *where high risk is known* (i.e., for jobs known to possess high strength demands). Strength testing does not appear to predict the risk of injury or disease to an individual when job demands are low or moderate.

It should be clear from the preceding arguments that worker selection procedures are not the preferred method of reducing the risk of WMSDs, and they should not be applied indiscriminantly in the workplace. Instead, care must be exercised to ensure that these strength testing procedures are applied only in select circumstances. This procedure appears to be effective only when jobs are: known to entail high strength demands, and only when the worker's strength is evaluated in the context of those demands. However, if attention is paid to these limitations, worker selection can be an effective tool to decrease the risk of WMSDs.

Job Design

Physical strength assessment in ergonomics can also be used in *job design*. Job design has been a primary focus of the psychophysical method of determining acceptable weights and forces. Rather than determining *individual* worker strength capabilities and comparing these to job demands, the psychophysical method attempts to determine workloads that are "acceptable" (a submaximal strength assessment) for *populations* of workers. Once the acceptable workloads for a population are determined, the job or task is designed to accommodate the vast majority of that population. For example, a lifting task might be designed by selecting a weight that is acceptable to 75% of females and 90% of males. Strength assessment in job design has been shown to be an effective method of controlling WMSDs. Proper design of manual tasks using psychophysical strength assessment has been estimated to reduce the risk of back injuries by up to 33%.[12]

Purpose of this Publication

Muscular strength is a complicated function that varies greatly depending on the assessment. As a result there is often a great deal of confusion and misunderstanding of the appropriate uses of strength testing in ergonomics. Not uncommonly, these techniques are misapplied by persons who are not thoroughly familiar with the inherent caveats and limitations of various strength assessment procedures. The purposes of this publication are (1) to familiarize the reader with the four most common strength assessment techniques used in ergonomics (isometric, isoinertial, psychophysical, and isokinetic); and (2) to describe the proper applications of these techniques in controlling WMSDs in the workplace.

Four chapters cover these four strength measurement techniques. Each chapter describes the strength measurement technique and reviews the relevant published data. Equipment considerations and testing protocols are described, and the utility of the tests in the context of ergonomics is also evaluated. Finally, each chapter concludes with a discussion of the measurement technique with regard to the Criteria for Physical Assessment in Worker Selection.[6] Each measurement technique is subjected to the following set of questions:

1. Is it safe to administer?
2. Does it give reliable, quantitative values?
3. Is it related to specific job requirements?
4. Is it practical?
5. Does it predict risk of future injury or illness?

This publication is intended as a resource for better understanding and proper application of these strength assessment techniques in the effort to reduce the risk of WMSDs.

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