Strength Testing

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1. INTRODUCTION

If we consider ergonomics to be an exercise in matching job demands to worker capabilities, one of the principal capabilities we must be concerned with is that of *human strength*. Our ability to evaluate different characteristics of muscular strength has increased dramatically over the past couple of decades with the development of new and increasingly sophisticated instrumentation. One would think that armed with such advanced techniques, we might be able to develop methods to conclusively identify workers at risk of injury in physically demanding jobs. Unfortunately, this has not yet proven to be the case. Instead, what these instruments have continued to point out is how intricate a function muscular strength really is, and how complicated and ambiguous its relationship is to musculoskeletal injury.

While we cannot just use isolated tests of strength to specify precisely who may be at risk of injury, studies have indicated that strength testing can be a useful tool for job design and, under certain circumstances, selection of workers for demanding jobs. However, because strength is such a complex phenomenon, there has often been some confusion regarding the proper application and interpretation of strength tests in ergonomics, especially among persons not thoroughly familiar with the limitations and caveats associated with the available procedures. The purpose of this chapter is to discuss some of the fundamental principles of strength assessment in ergonomics, so that these procedures can be better applied to control the risk of musculoskeletal disorders in the workplace.

1.1. What is Strength? (And what are we Measuring?)

Many of the complications associated with strength assessment arise from the simple fact that even our most sophisticated machinery *does not directly measure* the force or tension developed by a muscle in a living person. Instead, we can only observe the consequences of force development by a contracting muscle, or more likely, by a *combination* of muscles. There are many ways in which we can measure the effects of muscular contraction, and the techniques we use can have a dramatic impact on the strength readings we will obtain. Consider the situation illustrated in Figure 1. In this example, the muscle exerts a constant force of 1000 Newtons (N). However, the forces we measure can vary quite dramatically depending on where we place the force cuff — from 167 N if we place it near the wrist to 500 N if we place it near the elbow. Which value should we select as properly representing the muscular strength for this elbow flexion exertion?

The preceding example illustrates some important points with regard to strength assessment. Perhaps the most important is that "muscular strength is what is measured by an instrument" (Kroemer *et al.* 1990). It should also be clear from this example

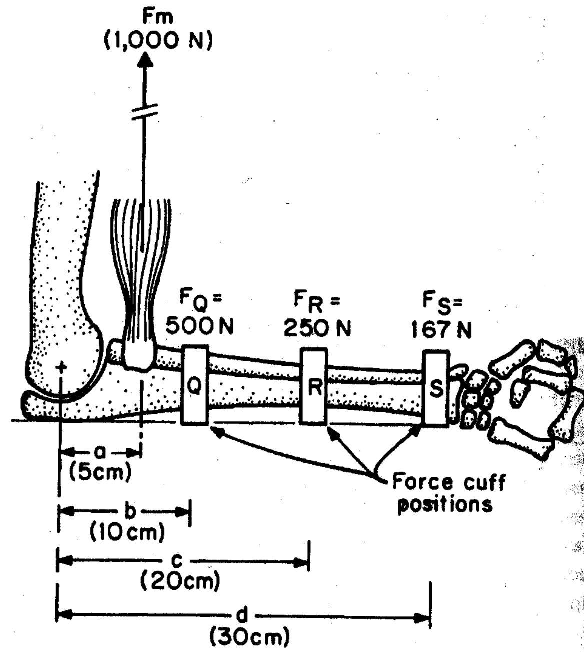

Figure 1. Given a constant muscle force (F_m), forces measured at various distances from the elbow will result in different force readings (F_Q, F_R or F_S).

that two researchers could perform an elbow flexion strength experiment on the same group of subjects, but if each selected different force cuff positions, they might end up with wildly differing estimates of strength. Differences in the strengths of various muscle groups in the published literature may be the results of differences in the procedures and measurement methods used by the experimenters. Thus, it is critical that any strength data presented be accompanied by a detailed account of the manner in which the data were obtained.

A few additional points need to be made with regard to the testing of human strength. We must be clear that what we are obtaining in such tests are not a person's maximal strength capability, but their maximal *voluntary* strength. The voluntary nature of the exertion introduces an unknown, but surely substantial, amount of variability in our measurements of strength. One can imagine two subjects with identical muscular strength capabilities, but with varying levels of motivation or discomfort tolerance, for example. We are likely to observe considerable differences in the voluntary force exerted by the two, but it should be understood that such results may be largely the result of psychological factors, and not differences in muscular strength *per se*. The important point to be made here is that not only are we unable to directly measure muscular force, what we *are* able to measure is modified by an invisible filter — a filter subject to a wide variety of influences and which will differ considerably for every person we test. To make matters worse, this filter would be expected to change even within a given individual on a given day. From the foregoing discussion, one can perhaps better appreciate some of the difficulties with establishing a definitive relationship between an individual's measured strength and that individual's risk of injury.

2. PURPOSES OF STRENGTH ASSESSMENT IN ERGONOMICS

There are a number of reasons people may want to collect human strength data. This article will discuss two of the most common uses of physical strength assessment in ergonomics: *job design* and *worker selection.*

2.1. Job Design

Probably the most effective use of worker strength evaluations is in the area of job design. Job design has been a primary focus of the psychophysical method of determining acceptable weights and forces. 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. It has been estimated that this approach to the design of lifting tasks might reduce the risk of back injuries by up to 33%.

2.2. Worker Selection

The purpose of worker selection and placement programs is to ensure that jobs which involve heavy physical demands are not performed by those lacking the necessary strength capabilities. It should be noted that this method is not the preferred strategy of the ergonomist, but is a provisional measure for the control of work-related musculoskeletal disorders (WMSD) where 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. These principles are: (1) ensuring that the strength measures are related to the demands of the job, and (2) that strength assessment is performed only under circumstances where they can predict who may be at risk of WMSD. The literature has shown that worker selection is *only effective when a worker's strength capacity is equated with the demands of the job*. All too often, emphasis is placed on collecting data on the former attribute, while the latter receives little or no attention. The second issue that must be considered when worker selection is to be implemented is that of the test's *predictive value*. The predictive value of a test is a measure of its ability to determine who is at risk of future WMSD. In the case of job-related strength testing, the predictive value appears to hold only when testing individuals for jobs *where high risk is known*. Strength testing does not appear to predict the risk of injury or disease to an individual when job demands are low or moderate.

3. TYPES OF MUSCULAR STRENGTH ASSESSMENT AND THEIR USE IN ERGONOMICS

Muscular exertions can be divided into those which produce motion about a joint (dynamic exertions), and those which do not (isometric or static exertions). The vast majority of occupational tasks involve dynamic motions. Unfortunately, the complexity of such motion makes it more difficult to quantify. Static exertions, on the other hand, are easier to control and measure, but may be inappropriate to apply in situations where dynamic activity is present. Neither mode of strength testing is inherently better than the other — the key is to make sure that the test that is used relates to the application being studied. The following sections briefly describe the most common strength analysis techniques used in ergonomics. The first deals with isometric strength testing, the remaining sections describe various dynamic tests of strength. Greater detail on these strength assessment procedures can be found elsewhere (Gallagher *et al.* 1998).

3.1. Analysis of Isometric Strength

When a worker is called upon to perform a physically demanding lifting task, moments (or torques) are produced about various joints of the body by the external load. Often these moments are augmented by the force of gravity acting on the mass of various body segments. For example, in a biceps curl exercise, the moment produced by the forearm flexors must counteract the moment of the weight held in the hands, as well as the moment caused by gravity acting on the center of mass of the forearm. In order to successfully perform the task, the muscles responsible for moving the joint must develop a greater moment than that imposed by the combined moment of the external load and body segment. It should be clear that for each joint of the body, there exists a limit to the strength that can be produced by the muscle to move ever increasing external loads. This concept has formed the basis of isometric muscle strength prediction modeling.

The following procedures are generally used in this biomechanical analysis technique. First, workers are observed (and usually photographed or videotaped) during the performance of physically demanding tasks. For each task, the posture of the torso and the extremities are documented at the time of peak exertion. The postures are then re-created using a computerized software package, which calculates the load moments produced at various joints of the body during the performance of the task. The values obtained during this analysis are then compared to population norms for isometric strength obtained from a population of industrial workers. In this manner,

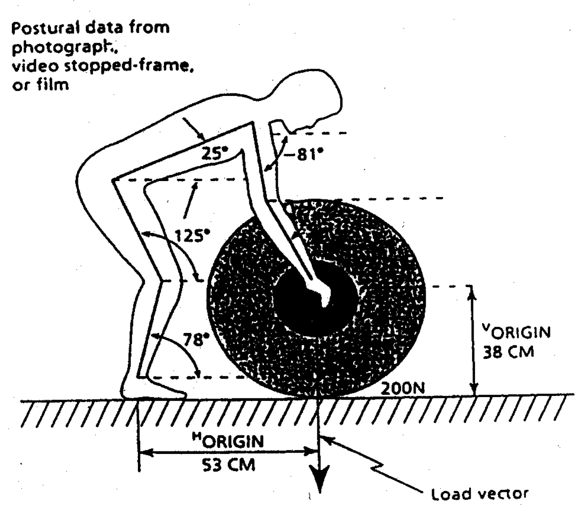

Figure 2. Postural data required for analysis of joint moment strengths using the isometric technique.

the model can estimate the proportion of the population capable of performing the exertion, as well as the predicted compression forces acting on the lumbar discs resulting from the task (Chaffin and Andersson 1991).

3.2. Iso-inertial Methods

3.2.1. The strength aptitude test

The Strength Aptitude Test (SAT) is a classification tool for matching the physical strength abilities of individuals with the physical strength requirements of jobs in the Air Force (McDaniel *et al.* 1983). The SAT is given to all Air Force recruits as part of their pre-induction examinations. Results of the SAT are used to determine whether an individual possesses the minimum strength criterion which is a prerequisite for admission to various Air Force Specialties (AFS). The physical demands of each AFS are objectively computed from an average physical demand weighted by the frequency of performance and the percent of the AFS members performing the task. Objects weighing less than 10 pounds are not considered physically demanding and are not considered in the job analysis. Prior to averaging the physical demands of the AFS, the actual weights of objects handled are converted into equivalent performance on the incremental weight lift test using statistical procedures developed over years of testing. These relationships consider the type of task (lifting, carrying, pushing, etc.), the size and weight of the object handled, as well as the type and height of the lift. Thus, the physical job demands are related to, but are not identical to, the ability to lift an object to a certain height. Job demands for various AFS are re-analyzed periodically for purposes of updating the SAT.

In this technique, a preselected mass, constant in each test, is lifted by the subject using a device such as that shown in Figure 3. The amount of weight to be lifted is relatively light at first, but the amount of mass is continually increased in succeeding tests until it reaches the maximal amount that the subject voluntarily indicates s/he can handle. A unique aspect of this technique is that it is the only strength measurement procedure discussed in this document where results are based on the success or failure to perform a prescribed criterion task. The criterion tasks studied have typically included lifting to shoulder height, elbow height or knuckle height.

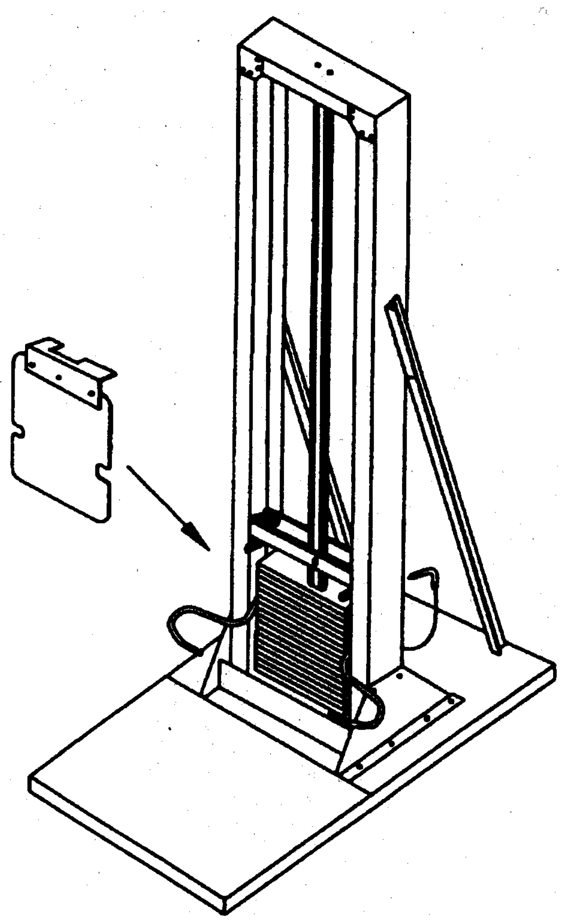

Figure 3. Incremental Weight Lift Machine. The barrier has been removed to expose the hidden stack of weights.

3.2.2. Psychophysical strength assessment

As mentioned previously, job design has been a primary focus of the psychophysical method of determining acceptable weights and forces. In this technique, subjects are typically asked to adjust the weight or force associated with a task in accordance with their own perception of what is an *acceptable workload* under specified test conditions. It can be seen from this description that this technique does not attempt to evaluate the maximum forces a subject is capable of producing. Instead, this procedure evaluates a type of "submaximal," endurance-based estimate of acceptable weights or forces.

In the context of lifting tasks, the following procedure is usually used in psychophysical strength assessments. The subject is given control of one variable, typically the amount of weight contained in a lifting box. There will usually be two 20-min periods of lifting for each specified task: one starting with a light box (to which the subject will add weight), the other starting with a heavy box (from which the subject will extract weight). The box will have a hidden compartment containing an unknown (to the subject) amount of weight, varied before each test, to prevent visual cues to the subject regarding how much weight is being lifted. The amount of weight selected during these two sessions is averaged and is taken as the maximum acceptable weight of lift for the specified conditions. In psychophysical assessments, the subject is instructed to work consistently according to the concept of "a fair day's pay for a fair day's work": working as hard as s/he can without straining himself, or becoming unusually tired, weakened, overheated, or out of breath. As psychophysical strength data is collected on large numbers of subjects, it becomes possible to design jobs so that they are well within the strength capabilities of the vast majority of workers. One criterion that is often used is to design the job so that 75% of workers rate the load as acceptable. Studies have indicated that if workers lift more than this amount, they may be three times more likely to experience a low back injury. On the other hand, designing jobs in accordance with this criterion has the potential to reduce the occurrence of low back injuries by up to 33% (Snook and Ciriello 1991).

3.3. Isokinetic Strength

A technique of dynamic testing that has been growing in popularity is that dealing with the measurement of isokinetic strength. As defined previously, this technique evaluates muscular strength throughout a range of motion and at a constant velocity. It is important to realize that people do not normally move at a constant velocity. Instead, human movement is usually associated with significant acceleration and deceleration of body segments. Thus, there is a perceptible difference between isokinetic strength and free dynamic lifting. In the latter instance, subjects may use rapid acceleration to gain a weight lifting advantage. Acceleration is not permitted in isokinetic tests of strength.

The majority of isokinetic devices available on the market focus on quantifying strength about isolated joints or body segments, for example, trunk extension and flexion. This may be useful for rehabilitation or clinical use, but isolated joint testing is generally not appropriate for evaluating an individual ability to perform occupational lifting tasks. One should not make the mistake of assuming, for instance, that isolated trunk extension strength is representative of an individuals ability to perform a lift. In fact, lifting strength for a task may be almost entirely unrelated to trunk muscle strength. Strength of the arms or legs (and not the trunk) may be the limiting factor in an individuals lifting strength. For this reason, machines that measure isokinetic strengths of isolated joints or body segments should not be used as a method of evaluating worker capabilities related to job demands in most instances.

Many investigators have used dynamic isokinetic lifting devices specifically designed to measure whole-body lifting strength. These devices typically have a handle connected by a rope to a winch, which rotates at a specified isokinetic velocity when the handle is pulled (Figure 4). Studies using this type of

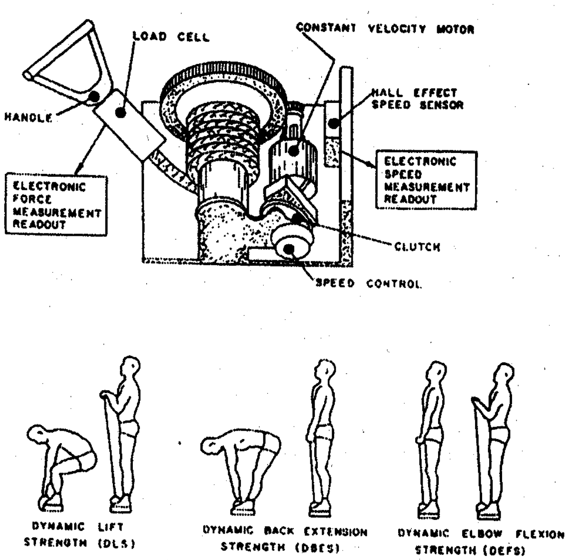

Figure 4. An isokinetic device allowing assessment of various muscular strengths (such as those shown) at a constant velocity.

device have demonstrated good correlations between isokinetic Dynamic Lift Strength (i.e. a lift from floor to chest height) and the maximum weights individuals were willing to lift for infrequent tasks using the psychophysical approach (Pytel and Kamon 1981). Thus, under certain circumstances, this device appears to possess some validity for assessment of job related dynamic lifting strength capabilities of individuals. Some investigators have attempted to modify this type of instrument by providing a means to mount it so that isokinetic strength can be measured in vertical, horizontal, and transverse planes. However, while advances have been made in the use of isokinetic devices for worker strength evaluation, this procedure cannot be thought to be fully developed in the context of worker selection procedures.

4. CONCLUSIONS

In spite of advances in measurement techniques and an explosive increase in the volume of research, our understanding of human strength remains in its introductory stages. It is clear that muscle strength is a highly complex and variable function dependent on a large number of factors. It is not surprising, therefore, that there are not only substantial differences in strength between individuals, or that strength measurements for a single individual can vary a great deal even during the course of a single day. Strength is not a fixed attribute — strength training regimens can increase an individual's capability by 30–40% or more. Disuse can lead to muscle atrophy.

The use of physical strength assessment in ergonomics has focused on both job design and worker selection techniques. Of these, the former has a much greater potential to significantly reduce WMSD. Worker selection techniques must be considered a method of last resort — where engineering changes or administrative controls cannot be used to reduce worker exposure to WMSD risk factors. This technique has only shown a moderate effect in truly high-risk environments, and only in short-term studies. It is not known whether worker selection procedures have a protective effect over the long-term.

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