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Isometric, Isoinertial, and Psychophysical Strength Testing: Devices and Protocols

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ABSTRACT Many jobs in industry place severe demands on the worker's musculoskeletal system — demands that may approach or exceed worker voluntary strength capabilities. There is evidence to suggest that such jobs increase the likelihood that the worker will experience a musculoskeletal disorder. For this reason, a great deal of effort has recently been focused on the development of methods to evaluate muscular strength capabilities of workers, both for purposes of ergonomic job design and for the development of worker selection procedures. However, the necessity of using indirect measures of muscular strength makes its assessment quite complex, which has sometimes led to confusion and misunderstanding regarding appropriate uses of strength measurement techniques. The purpose of this chapter is to provide information regarding the appropriate procedures for the measurement and reporting of strength test results for three common measurement techniques used in ergonomics (isometric, isoinertial, and psychophysical). It is hoped that the information contained in this chapter will provide the reader with a better understanding of the advantages, disadvantages, caveats, and limitations associated with the use of these strength assessment techniques.

8.1 Ergonomic Relevance

An understanding of the muscular strength characteristics of both individuals and populations can assist the ergonomist in developing appropriate interventions to reduce musculoskeletal disorder risk. Numerous strength assessment techniques exist for this purpose. However, muscular strength is a complicated function, and failure to adhere to established principles of measurement and analysis can lead to gross misinterpretation of test results. This chapter describes three strength assessment techniques commonly used by ergonomists (i.e., isometric, isoinertial, and psychophysical) and discusses issues important to proper assessment of muscular strength for each of these techniques.

8.2 Introduction

Muscular strength is a complicated function that can vary greatly depending on the methods of assessment. As a result, there is often a great deal of confusion and misunderstanding of the appropriate uses of strength testing in ergonomics. It is not uncommon to see these techniques misapplied by persons who are not thoroughly familiar with the caveats and limitations inherent with various strength assessment procedures. The purposes of this chapter are: (a) to familiarize the reader with three common techniques of strength assessment used in ergonomics (isometric, isoinertial, and psychophysical) and (b) to describe the proper applications of these techniques in the attempt to control work-related musculoskeletal disorders (WMSDs) in the workplace.

This chapter contains three sections, one for each of the strength measurement techniques listed above. Each section 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 section concludes with a discussion of the measurement technique with regard to the Criteria for Physical Assessment in Worker Selection (Chaffin and Andersson, 1991). In this discussion, 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?

It is hoped that this chapter will provide a resource that can be used to better understand and properly apply these strength assessment techniques in the effort to reduce the risk of WMSDs.

8.3 Isometric Strength

Isometric strength is defined as the capacity to produce force or torque with a voluntary isometric [muscle(s) maintain(s) a constant length] contraction. The key thing to understand about this type of contraction and strength measurement is that there is no body movement during the measurement period. The tested person's body angles and posture remain the same throughout the test.

Isometric strength has historically been the one most studied and measured. It is probably the easiest to measure and the easiest to understand. Some strength researchers feel that isometric strength data may be difficult to apply to some "real life" situations, because in most real circumstances people are moving — they are not static. Other researchers counter that it is equally difficult to determine the speed of movement of a person or group of persons doing a job (they all move in their own unique manners and at their own speed across the links and joints of the body). Thus, dynamic strength test data collected on persons moving at a different speed and/or in a different posture from the "real world" condition will be just as hard to apply. In truth, neither is better — they are different measurements, and both researchers and users should collect/use data which they understand and which fits their application.

8.3.1 Workplace Assessment

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 (Chaffin and Andersson, 1991). 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 (Chaffin and Andersson, 1991).

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, 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 disks resulting from the task.

Figure 8.1 shows an example of the workplace analysis necessary for this type of approach. Direct observations of the worker performing the task provide the necessary data. For example, the load magnitude and direction must be known (in this case, a 200-N load acting downward), as well as the size of the worker, the postural angles of the body (obtained from photographs or videotape), and whether the task requires one or two hands. Furthermore, the analysis requires accurate measurement of the load center relative to the ankles and the low back. A computer analysis program can be used to calculate the strength requirements for the task and the percentage of workers who would be likely to have sufficient strength capabilities to perform it. Results of this particular analysis indicate that the muscles at the hip are most stressed, with 83% of men having the necessary capabilities, but only slightly more than half of women would have the necessary strength in this region. These results can then be used as the basis for determining those workers who have adequate strength for the job. However, such results can also be used as ammunition for recommending changes in job design (Chaffin and Andersson, 1991).

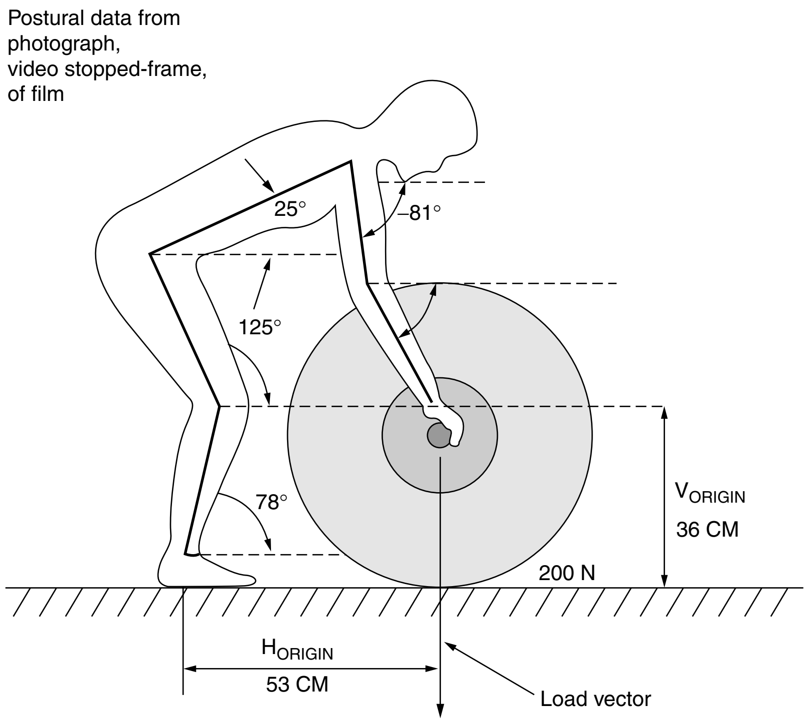

FIGURE 8.1
Postural data required for analysis of joint moment strengths using the isometric technique. (With permission of The Regents of The University of Michigan.)

8.3.2 The Isometric Testing Protocol

The basic testing protocol for isometric strength testing was developed by Caldwell et al. (1974) and published in an AIHA Ergonomics Guide by Chaffin (1975). The protocol outlined herein includes additional information determined by researchers since that time. When conducting isometric testing, there are a number of factors that must be considered and controlled (if possible) to avoid biased results. These factors include the equipment used to make the measurements, the instructions given to the person tested, the duration of the measurement period, the person's posture during the test, the length of the rest period between trials, the number of trials a person is given for each test, the tested person's physical state at the time of testing, the type of postural control used during the tests, and the environmental conditions during the test.

8.3.2.1 Test Duration

The length of an isometric strength test can impact the result in two ways. If it is too long, the subjects will fatigue and their strength scores will decline. If it is too short, the subjects will not reach their maximum force level before the test is terminated. The existing AIHA Guide suggests a four-second test, with the score being the average strength displayed during the second through fourth seconds. The appropriate three-second period can be determined as follows.

If the measuring equipment has the capability, collect strength data by having the subjects begin their contraction with the equipment monitoring the force until some preselected threshold is reached (usually 20 to 30% below the expected maximum force for the person and posture). Have equipment wait one second, and then have the equipment average the displayed force for the next three seconds. This is easily done with computerized systems.

If the equipment does not have the above capability, then have the person tested begin the test and gradually increase force over a one-second period. The force should be measured and averaged over the next three seconds. In complex whole-body tests, where multiple functional muscle groups are involved, it may take individuals a few seconds to reach their maximum. Under these conditions, the data collectors must adjust the premeasurement time interval accordingly, and they must carefully monitor the progress of the testing to insure that they are, in fact, measuring the maximal force during the three-second period.

8.3.2.2 Instructions

The instructions to the person tested should be factual, include no emotional appeals, and be the same for all persons in a given test group. This is most reliably accomplished with standardized written instructions, since the test administrator's feelings about the testee or the desired outcome may become evident during verbal instruction.

The following additional factors should also be considered. The purpose of the test, the use of the test results, the test procedures, and the test equipment should be thoroughly explained to the persons tested. Generally, the anonymity of the persons tested is maintained, but if names may be released, the tested person's written permission must be obtained. Any risks inherent to the testing procedure should be explained to the persons tested, and an informed consent document should be provided to, and signed by, all participating persons. All test participants should be volunteers.

Rewards, performance goals, encouragement during the test (for example "pull, pull, pull, you can do it, etc."), spectators, between-person competition, and unusual noises will all affect the outcome of the tests and must be avoided. Feedback to the tested person should be positive and qualitative. Feedback should not be provided during the test exertion, but may be provided after a trial or test is complete. No quantitative results should be provided during the testing period, because they may change the person's incentive and, thus, the test result.

To the tested person, a four-second maximal exertion seems to take a long time. During the test, feedback in the form of a slow four count or some other tester–testee agreed upon manner should be provided so the tested person knows how much longer a test will last.

8.3.2.3 Rest Period Length

Persons undergoing isometric strength testing will generally be performing a series of tests, with a number of trials for each test. Under these conditions, a person could develop localized muscle fatigue, and this must be avoided, since it will result in underestimating strength. Studies by Schanne (1972) and Stobbe (1982) have shown that a minimum rest period of two minutes between trials of a given test or between tests is adequate to prevent localized muscle fatigue. The data collector must be alert for signs of fatigue, such as a drop in strength scores as a test progresses. The person tested must be encouraged to report any symptoms of fatigue, and the rest periods should be adjusted accordingly. Whenever possible, successive tests should not stress the same muscle groups.

8.3.2.4 Number of Trials for Each Test

The test-retest variability for this type of testing is about 10%. It is higher for people with limited experience either with isometric testing or with forceful physical exertion in general. In addition, these people will often require a series of trials of a test to reach their maximum. The use of a single trial of a test will generally underestimate a person's maximum strength, and may underestimate it by more than 50%. A two-trial protocol results in less of an underestimate, but it may still exceed 30% (Stobbe and Plummer, 1984).

For this reason, the preferred approach to determining the number of trials for each test is to make the choice on the basis of performance. Begin by having the subject perform two trials of the test. The two scores are then compared, and if they are within 10% of each other, the highest of the two values is used as the estimate of the person's maximal strength, and you proceed to the next test. If the two values differ by more than 10%, additional trials of the same test are performed until the two largest values are within 10% of each other. Using this approach, Stobbe and Plummer (1984) averaged 2.43 trials per test across 67 subjects performing an average of 30 different strength tests. In any case, a minimum of two trials is needed for each test.

8.3.2.5 When to Give Tests

A person's measured strength is, for a variety of reasons, somewhat variable. It will not be constant over time, or over a workday. However, in the absence of specific muscle strength training, it should remain within a relatively narrow range. It is generally higher at the beginning of a workday than at the end. The fatigue-induced strength decrement will vary from person to person and will depend on the nature of the work done during the day. A person who performs repetitive lifting tasks all day can be expected to have a large lifting strength decrement over a workday, whereas a sedentary worker should have little or no decrement. Based on these results, the fairest evaluation of a person's maximum strength can be done at the beginning of, or at least early in, a workday.

8.3.2.6 Test Posture

Measured strength is highly posture dependent. Even small changes in the body angles of persons being tested and/or changes in the direction of force application can result in large changes in measured strength. When collecting strength data, a researcher should first determine what type of data is sought, and then one or more strength tests that will provide that specific type of data should be designed. If, for example, the test is being done to determine whether people are physically fit for a job, the test posture should emulate, to the extent possible, the posture required on the job.

Once the test posture has been determined, the researcher must insure that the same posture is used on each trial of the test. The researcher must monitor the test to insure that the person's posture does not change during the test. If these things are not done, the test results will be erratic and may seriously overestimate or underestimate the person's actual maximal strength.

8.3.2.7 Restraint Systems

Restraint systems are generally used either to confine a person to the desired test posture, or to isolate some part of the tested person's body so that a specific muscle group (or groups) can be tested (see Figure 8.2). In addition, restraint systems help to assure that all persons participating in a given study will be performing the same test. The type and

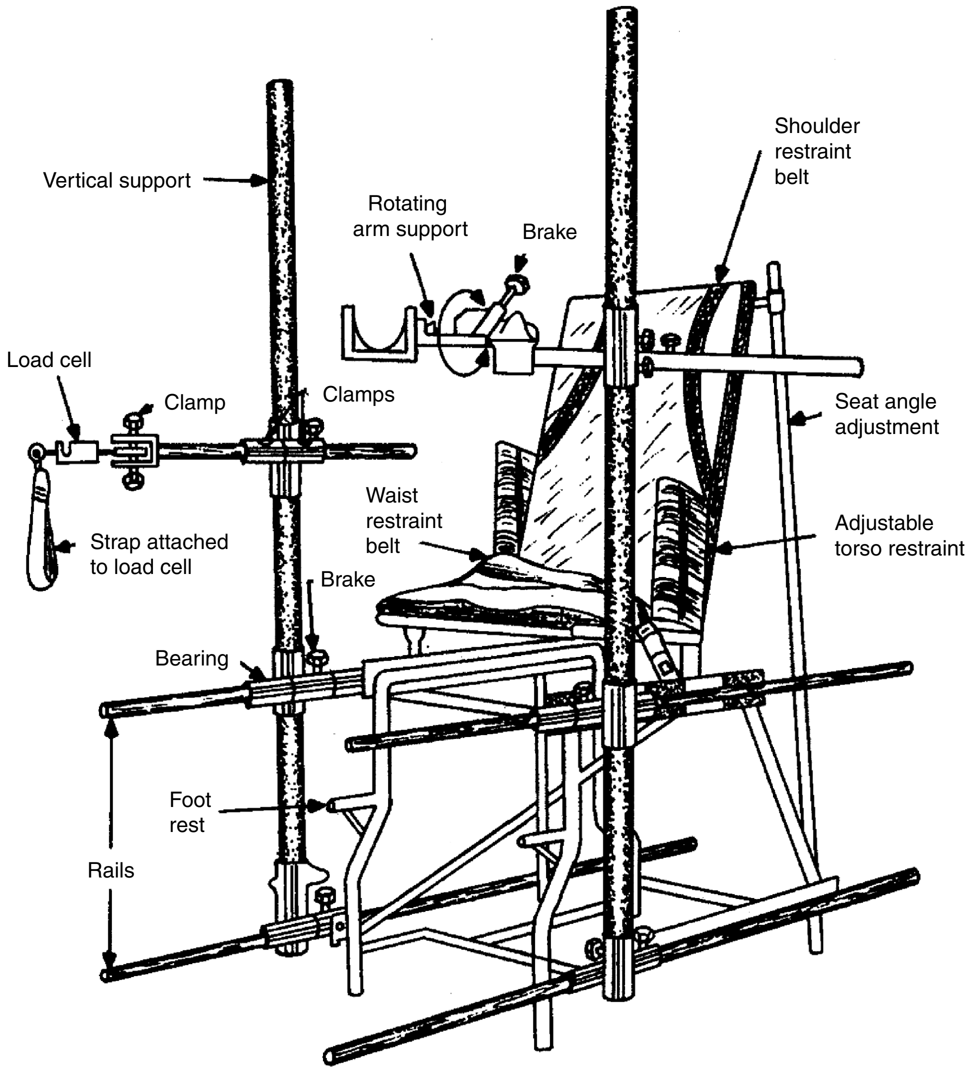

FIGURE 8.2
Example of a test fixture designed to restrain various body segments during isometric strength testing. (From *Occupational Biomechanics*, Chaffin, D.B. and G.B.J. Andersson, © 1991 by John Wiley & Sons. Reprinted by permission of John Wiley & Sons.)

location of restraint system used can have a major impact on test results. Similarly, the lack of a restraint system can allow the posture to vary or allow the use of the wrong or additional muscle groups, both of which will impact test results.

Any restraint system used should be comfortable. It should be padded in a manner that prevents local tissue stress concentrations during the test. It should be positioned so that the correct muscle group(s) and posture(s) are used and maintained. This latter item often requires some experimentation to correctly achieve.

For many strength tests, the use of a restraint system will be necessary if consistent and meaningful results are to be achieved. Researchers reporting strength testing results should describe the restraints used and their location in detail, so that other researchers and persons applying their data will be able to interpret it correctly. The nonuse of restraints should also be reported.

8.3.2.8 Environmental Conditions

The environmental conditions selected for the testing periods should be appropriate to the purpose of the test. For most testing, the environmental conditions found in a typical office building or medical department will be acceptable. In some cases, the effects of the environment on measured strength or physical performance must be determined, and then appropriate conditions can be established (e.g., worksites requiring exposure to hot or cold temperature extremes).

8.3.2.9 Equipment

Isometric strength testing equipment has not been standardized. Any equipment that has the capability to perform the necessary timing and averaging described above under "test duration" is probably acceptable. Today, this varies from dedicated force measurement devices such as the force monitor developed in the 1970s at University of Michigan, to a force transducer coupled to a PC via an A to D converter and managed by appropriate software, to complex multiple-mode strength-measuring devices manufactured by companies like Cybex, Chattex, Loredan, and Isotechnologies. The associated prices vary from one thousand plus dollars to as high as fifty to one hundred thousand dollars.

Equipment price is not the issue. Rather, it is equipment function that is at issue. Researchers should select or build equipment suited to their needs. Researchers must also understand what is happening inside the device (and its associated software) that they are using, so that the data they collect can be properly interpreted.

The human–equipment interface is another matter that can impact the test results. The interface must be appropriate to the task measured, it should be comfortable (unless discomfort effects are being studied), and it should give the person tested a sense of security about the test. Persons will generally be providing a maximal exertion in a situation where there is no movement. If they fear that the testing system may fail or move unexpectedly, they will not give a maximal performance. Similarly, the equipment must be strong enough to remain intact under the maximum load placed on it. If it fails unexpectedly, someone is going to be injured — perhaps severely.

8.3.2.10 Subjects

The subjects selected for strength testing will determine the results obtained. This means that when strength data are collected, the selection of subjects must appropriately represent the population it claims to describe (for example, design data for retired persons should be collected on retired persons, and design data for entry-level construction workers should be collected on young healthy adults).

For general research purposes, persons participating in a strength-testing project should not have a history of musculoskeletal injuries. There are other medical conditions, including hypertension, which may pose a threat of harm to a participant. Whenever possible, prospective participants should be medically evaluated and approved before participating in a strength-testing project.

The following data should be provided about the subject population when reporting strength testing results:

1. Gender
2. Age distribution
3. Relevant anthropometry (height, weight, etc.)
4. Sample size

5. Method by which sample was selected and who it is intended to represent
6. Extent of strength training done by participants, and their experience with isometric testing
7. Health status of participants (medical exam and/or questionnaire recommended)

8.3.2.11 Isometric Strength Data Reporting

The minimum data which should be reported for strength testing projects are:

1. Mean, median, and mode of data set
2. Standard deviation of data set
3. Skewness of data set (or histogram describing data set)
4. Minimum and maximum values

8.4 Evaluation of Isometric Strength Testing According to Physical Assessment Criteria

A set of five criteria have been purposed to evaluate the utility of all forms of strength testing. Isometric strength testing is evaluated with respect to these criteria in the following sections.

8.4.1 Is It Safe to Administer?

Any form of physical exertion carries with it some risk. The directions for the person undergoing an isometric test specifically state that participants should slowly increase the force until they reach what they feel is a maximum, and to stop if at any time during the exertion they feel discomfort or pain. The directions also expressly forbid jerking on the equipment. When isometric testing is performed in this manner it is quite safe to administer, because the tested person is deciding how much force to apply, over what time interval, and how long to apply it. The only known complaints relating to participation in isometric testing are some residual soreness in the muscles that were active in the test(s), and this is rarely reported.

8.4.2 Does the Method Provide Reliable Quantitative Values?

The test-retest variability for isometric testing is 5 to 10%. In the absence of a specific strength-training program, individual isometric strength remains relatively stable over time. When the number of trials is based on the 10% criterion discussed earlier, the recorded strength is near or at the tested person's maximum voluntary strength. Assuming the above factors, if test postures are properly controlled, isometric strength testing is highly reliable and quantitative.

8.4.3 Is the Method Practical?

Isometric strength testing has already been used successfully in industry for employee placement, in laboratories for the collection of design data, and in rehabilitation facilities for patient progress assessment.

8.4.4 Is the Method Related to Specific Job Requirements (Content Validity)?

Isometric strength testing can be performed in any posture. When it is conducted for employee placement purposes, the test postures should be as similar as possible to the postures that will be used on the job. The force vector applied by the tested person should also be similar to the force vector that will be applied on the job. When these two criteria are met, isometric strength testing is closely related to job requirements. However, it should be noted that results obtained using isometric strength testing loses both content and criterion-related validity as job demands become more dynamic.

8.4.5 Does the Method Predict the Risk of Future Injury or Illness?

A number of researchers have demonstrated that isometric strength testing does predict risk of future injury or illness for people on physically stressful jobs (Chaffin et al., 1978; Keyserling et al., 1980). The accuracy of this prediction is dependent on the quality of the job evaluation on which the strength tests are based and the care with which the tests are administered.

8.5 Isoinertial Strength Testing

Kroemer (1982, 1983, 1985) and Kroemer et al. (1990) define the isoinertial technique of strength assessment as one in which *mass properties of an object are held constant*, as in lifting a given weight over a predetermined distance. Several strength assessment procedures possess the attribute in this definition. Most commonly associated with the term is a specific test developed to provide a relatively quick assessment of a subject's maximal lifting capacity using a modified weight lifting device (Kroemer, 1982; McDaniel et al., 1983). The classic psychophysical methodology of assessing maximum acceptable weights of lift is also an isoinertial technique under this definition (Snook, 1978).

While the definition provided by Kroemer (1982) and Kroemer et al. (1990) has been most widely accepted in the literature, some have applied the term "isoinertial" to techniques that differ somewhat from the definition given above, such as in a description of the Isotechnologies B-200 strength testing device (Parnianpour et al., 1988). Rather than lifting a constant mass, the B-200 applies a constant force against which the subject performs an exertion. The isoinertial tests described in this paper apply to situations in which the mass to be moved by a musculoskeletal effort is set to a constant.

8.5.1 Is Isoinertial Testing Psychophysical, or Is Psychophysical Testing Isoinertial?

As various types of strength tests have evolved over the past few decades, there have been some unfortunate developments in the terminology that have arisen to describe and/or classify different strength assessment procedures. This is particularly evident when one tries to sort out the various tests that have been labeled "isoinertial." One example was cited above. Another problem that has evolved is that the term "isoinertial strength" has developed two different connotations. The first connotation is the conceptual definition — isoinertial strength tests describe any strength test where a constant mass is handled. However, in practice, the term is often used to denote a *specific* strength test where subjects' maximal lifting capacity is determined using a machine where a constant mass is lifted

(Kroemer, 1982; McDaniel et al., 1983). Partially as a result of this dual connotation, the literature contains references both to the "isoinertial strength test" as a psychophysical variant (Ayoub and Mital (1989) and to the psychophysical method as an "isoinertial strength test"(Chaffin and Andersson, 1991; Kroemer et al., 1990). In order to lay the framework for the next two sections, the authors would like to briefly discuss some operational definitions of tests of isoinertial and psychophysical strength.

When Ayoub and Mital (1989) state that the isoinertial strength test is a variant of the psychophysical method, they refer to the specific strength test developed by Kroemer (1982) and McDaniel et al. (1983). Clearly, this isoinertial protocol has many similarities to the psychophysical method: both are dynamic; weight is adjusted in both; both measure the load a subject is willing to endure under specified circumstances, etc. However, while both deal with lifting and adjusting loads, there are significant differences between the psychophysical (isoinertial) technique and the Kroemer/McDaniel (isoinertial) protocol, both procedurally and in use of the data collected in these tests. For purposes of this paper we will designate the Kroemer/McDaniel protocol Maximal Isoinertial Strength Tests (MIST). This section deals with the latter isoinertial technique, which differs from the psychophysical technique on the following counts:

1. In Maximal Isoinertial Strength Tests, the amount of weight lifted by the subject is *systematically adjusted by the experimenter, primarily through increasing the load to the subject's maximum*. In contrast, in psychophysical tests, *weight adjustment is freely controlled by the subject, and may be upwards or downwards*.
2. The Maximal Isoinertial Strength Tests discussed in this section are designed to quickly establish an individual's *maximal strength* using a *limited number of lifting repetitions*; whereas psychophysical strength assessments are typically performed over a *longer duration of time* (usually at least 20 minutes), and instructions are that the subject select an *acceptable (submaximal) weight of lift*, not a maximal one. Due to the typically longer duration of psychophysical assessments, greater aerobic and cardiovascular components are usually involved in the acceptable workload chosen.
3. Isoinertial strength tests have traditionally been used as a *worker selection tool* (a method of matching physically capable individuals to demanding tasks). While psychophysical tests can and have been used for worker selection, the principle focus of psychophysical methods has been to establish data that can be used for the purpose of *ergonomic job design* (Snook, 1978).

8.5.2 Published Isoinertial Strength Data

The LIFTEST and SAT procedures are isoinertial techniques of strength testing that attempt to establish the maximal amount of weight that a person can safely lift (Kroemer, 1982). In these techniques a preselected mass, constant in each test, is lifted by the subject (typically from knee height to knuckle height, elbow height, or to overhead reach height). The amount of weight to be lifted is at first relatively light, but the amount of mass is continually increased in succeeding tests until it reaches the maximal amount that the subject voluntarily indicates he/she can handle. This technique has been used extensively by the U.S. Air Force (McDaniel et al., 1983) and is applicable to dynamic lifting tasks in industry as well (Jiang et al., 1986; Kroemer, 1982).

Since a constant mass is lifted in LIFTEST, the acceleration of the load during a test is dependent on the force applied to the load during the test (in accordance with Newton's Second Law: $F = ma$). The dynamic nature of this procedure, the fact that a constant mass

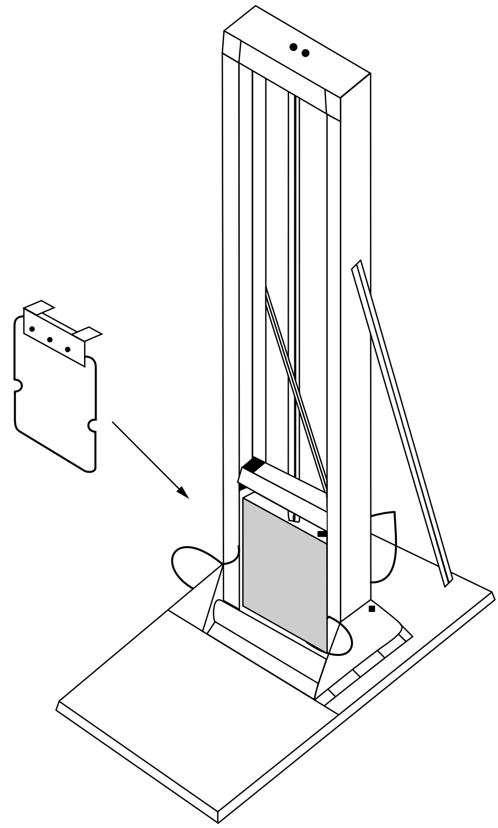

FIGURE 8.3
The Incremental Weight Lift Machine. The barrier has been removed to expose the stack of weights.

is being lifted, and the subject's freedom to choose the preferred lifting technique, all give the LIFTEST a general similarity to certain types of industrial lifting tasks. A unique aspect of the LIFTEST 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 (Jiang et al., 1986a; Kroemer, 1985; McDaniel et al., 1983; Ostrom et al., 1990), elbow height (Jiang et al., 1986a; Kroemer, 1985), or knuckle height (Jiang et al., 1986a; Kroemer, 1983). The USAF also developed a muscular endurance test using an Incremental Lift Machine (see Figure 8.3), or ILM (McDaniel et al., 1983).

The LIFTEST shoulder height maximal strength test has demonstrated the highest correlation with manual materials-handling activities (Jiang et al., 1986a), and has been subjected to a biomechanical analysis by Stevenson et al. (1990). Stevenson et al. (1990) demonstrated that this criterion task could be separated into three distinct phases: (1) a powerful upward pulling phase, where maximal acceleration, velocity, and power values are observed, (2) a wrist changeover maneuver (at approximately elbow height), where momentum is required to compensate for low force and acceleration, and (3) a pushing phase (at or above chest height), characterized by a secondary (lower) maximal force and acceleration profile.

The analysis by Stevenson et al. (1990) suggested that successful performance of the criterion shoulder-height lift requires a technique quite different from the concept of slow, smooth lifting usually recommended for submaximal lifting tasks. On the contrary, lifting

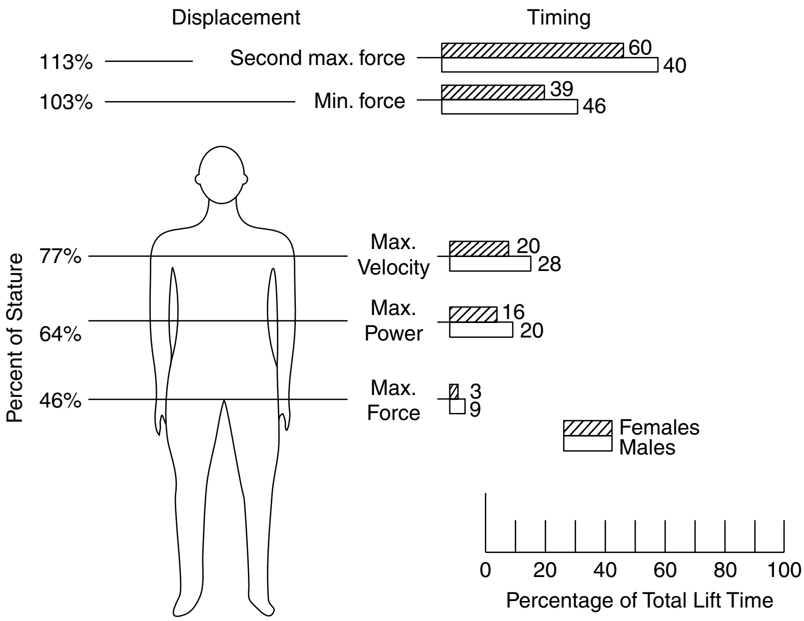

FIGURE 8.4
Displacement and timing parameters for a 1.83 m maximal isoinertial lift. Figure illustrates anatomical landmarks for the location of key events, found to be consistent for both genders. (From Stevenson, J.M., et al., *Ergonomics,* 33(2), 161–172, 1990. Reprinted with permission of Taylor and Francis.)

of a maximal load requires a rapid and powerful lifting motion. This is due in large part to the need to develop sufficient momentum to allow successful completion of the wrist changeover portion of the lift. Most lift failures occur during the wrist changeover procedure, probably the result of poor mechanical advantage of the upper limb to apply force to the load at this point in the lift. Stevenson et al. (1990) found that certain anatomical landmarks were associated with maximal force, velocity, and power readings (see Figure 8.4). Maximal force readings were found to occur at mid-thigh, maximal velocity at chest height, minimum force was recorded at head height, and the second maximal acceleration (pushing phase) was observed at 113% of the subject's stature.

8.5.2.1 The Strength Aptitude Test (McDaniel et al., 1983)

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, 1994). The SAT is given to all Air Force recruits as part of their preinduction examinations. Results of the SAT are used to determine whether the individual tested possesses the minimum strength criterion that is a prerequisite for admission to various Air Force Specialties (AFSs). 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 regression equations 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

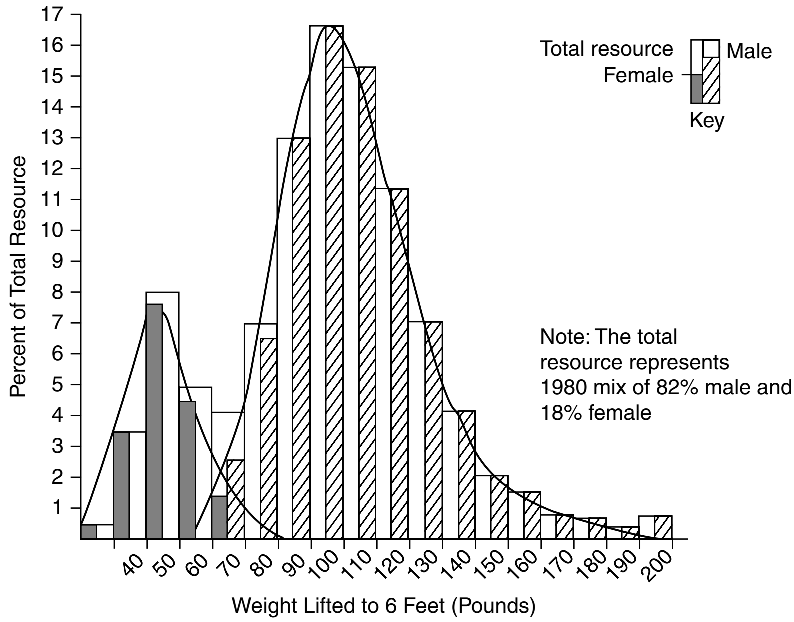

FIGURE 8.5
Distribution of weight lifted in a 1.83 m maximal isoinertial lift for male and female United States Air Force recruits. [Reprinted from McDaniel, J.W., R.J. Shandis, and S.W. Madole: *Weight Lifting Capabilities of Air Force Basic Trainees* (AFAMRL–TR–83–0001). Dayton, Ohio: Wright–Patterson AFBDH, Air Force Aerospace Medical Research Laboratory, 1983.]

identical to, the ability to lift an object to a certain height. Job demands for various AFSs are reanalyzed periodically for purposes of updating the SAT.

The first major report describing this classification tool was a study of 1671 basic trainees, including 1066 males and 605 females (McDaniel et al., 1983). The incremental weight-lift tests started with an 18.1-kg weight, which was to be raised to 1.83 m or more above the floor. This initial weight was increased in 4.5-kg increments until subjects were unable to raise the weight to 1.83 m. Maximal weight lift to elbow height was then tested as a continuation of the incremental weight-lift test. In the test of lifting the weight to 1.83 m, males averaged 51.8 kg (± 10.5 SD), while females averaged 25.8 kg (± 5.3). The respective weights lifted to elbow height were 58.6 kg (± 11.2) and 30.7 kg (± 6.3). The distributions of weight lifting capabilities for both male and female basic trainees in lifts to 6 feet are provided in Figure 8.5. Results of the elbow height lift are presented in Table 8.1. McDaniel et al. (1983) also performed a test of isoinertial endurance. This involved holding a 31.8-kg weight at elbow height for the duration the subject could perform the task. Male basic trainees were able to hold the weight for an average of 53.3 seconds (± 22.11), while female basic trainees managed to hold the weight an average of 10.3 seconds (± 10.5).

When developing the SAT, the Air Force examined more than 60 candidate tests in an extensive, four-year research program and found the incremental weight lift to 1.83 m to be the single best test of overall dynamic strength capability, which was both safe and reliable (McDaniel, 1994). This finding was confirmed by an independent study funded by the U.S. Army (Myers et al., 1984). This study compared the SAT to a battery of tests developed by the Army (including isometric and dynamic tests) and compared these with representative heavy demand tasks performed within the Army. Results showed the SAT to be superior to all others in predicting performance on the criterion tasks.

TABLE 8.1

Weight Lifted by Male and Female U.S. Air Force Recruits Using Maximal Isoinertial Lift to Elbow Height

	Males		Females	
Percentile	**Pounds**	**Kilograms**	**Pounds**	**Kilograms**
1	80	36.3	40	18.1
5	93	42.2	48	21.8
10	100	45.4	52	23.6
20	109	49.5	58	26.3
30	116	52.6	61	27.7
40	122	55.4	65	29.5
50	127	57.6	68	30.9
60	133	60.3	71	32.2
70	140	63.5	75	34.0
80	150	68.1	78	35.4
90	160	72.6	85	38.6
95	171	77.6	90	40.8
99	197	89.4	100	45.4
Mean	129	58.6	68	30.7
S.D.	25	11.2	14	6.3
Minimum	50	22.7	< 40	< 18.1
Maximum	> 200	> 90.7	100	49.9
Number	1066		605	

8.5.2.2 LIFTEST

Kroemer (1982, 1985) described results of a study using a similar apparatus to the one used by the U.S. Air Force. The sample consisted of 39 subjects (25 male) recruited from a university student population. The procedures were similar to McDaniel et al. (1983), with the exception that the minimum starting weight was 11.4 kg, and that maximal lifting limits were established to prevent overexertion. These were 77.1 kg for floor-to-knuckle-height tests, and 45.4 for floor-to-overhead-reach tests. The following procedure was used for establishing the maximal load: if the initial 11.4-kg weight was successfully lifted, the weight was doubled to 22.7 kg. Additional 11.4-kg increments were added, until an attempt failed or the maximal lifting limit was reached. If an attempt failed, the load was reduced by 6.8 kg. If this test weight was lifted, 4.5 kg was added; if not, 2.3 kg was subtracted. This scheme allowed quick determination of the maximal load the subject could lift.

In Kroemer's studies, 6 of 25 male subjects exceeded the cut-off load of 100 pounds (45.4 kg) in overhead reach lifts (Kroemer, 1982, 1985). All 14 females stayed below this limit. The 19 remaining male subjects lifted an average of 27 kg. The female subjects lifted an average of 16 kg. In lifts to knuckle height, 17 of the 25 male (but none of the female) subjects exceeded the 77.1 kg cut-off limit. The remaining subjects lifted an average of about 54 kg, with males averaging 62 kg and females 49 kg. The coefficients of variation for all tests were less than 8%. Summary data for this study are given in Table 8.2.

TABLE 8.2

Results of Maximal Isoinertial Strength Tests for 25 Male and 14 Female Subjects

	All				Male				Female			
	Mean	**SD**	**CV**	**N**	**Mean**	**SD**	**CV**	**N**	**Mean**	**SD**	**CV**	**N**
Overhead												
Liftest (kg)	27.0	10.3	3.5%	33	34.8	5.2	3.2%	19	16.3	3.7	3.9%	14
Lift > 45.5 kg	—	—	—	6	—	—	—	6	—	—	—	0
Knuckle												
Liftest (kg)	53.9	13.4	6.9%	22	62.2	7.8	5.2%	8	49.1	13.7	7.8%	14
Lift > 77 kg	—	—	—	17	—	—	—	17	—	—	—	0

8.5.3 Evaluation of Isoinertial Strength Tests According to Physical Assessment Criteria

8.5.3.1 Is It Safe to Administer?

The MIST procedures described above appear to have been remarkably free of injury. Isoinertial procedures have now been performed many thousands of times without report of verifiable injury. However, reports of transitory muscle soreness have been noted. The temporary muscle soreness associated with isoinertial testing has been similar to that experienced in isokinetic tests, but has been reported less frequently than that experienced with isometric strength tests.

McDaniel et al. (1983) present some useful recommendations for design of safe isoinertial weight-lift testing procedures. The following list summarizes the recommendations made by these authors.

1. Weight lifting equipment should be designed so that the weights and handle move only in a vertical direction.
2. Sturdy shoes should be worn, or the subject may be tested barefoot. Encumbering clothing should not be worn during the test.
3. The initial weight lifted should be low — 20 to 40 pounds. Weights in this range are within the capability of almost everyone. Weight increments should be small.
4. The upper limit should not exceed the largest job-related requirement or 160 pounds, whichever is less.
5. The starting handle position should be one to two feet above the standing surface. If the handle is lower, the knees may cause obstruction. If the handle is too high, the subjects will squat to get their shoulders under it prior to lifting. A gap between the handles will allow them to pass outside the subject's knees when lifting, allowing a more erect back and encouraging the use of leg strength.
6. The recommended body orientation prior to lifting should be (a) arms straight at the elbow, (b) knees bent to keep the trunk as erect as possible, and (c) head aligned with the trunk. The lift should be performed smoothly, without jerk.
7. A medical history of the subject should be obtained. If suspicious physical conditions are identified, a full physical examination should be performed prior to testing. Subjects over 50 years of age or pregnant should always have a physical prior to testing.

8. All sources of overmotivation should be minimized. Testing should be done in private and results kept confidential. Even the test subject should not be informed until the testing is completed.
9. If the subject pauses during a lift, the strength limit has been reached, and the test should be terminated. Multiple attempts at any single weight level should not be allowed.
10. The testing should always be voluntary. The subject should be allowed to stop the test at any time. The subject should not be informed of the criteria prior to or during the test.

It is noteworthy that, as of 1994, over 2 million subjects have been tested on the SAT without any back injury or overexertion injury (McDaniel, 1994).

8.5.3.2 Does the Method Provide Reliable, Quantitative Values?

Kroemer et al. (1985) reported LIFTEST coefficients of variation (measures of intra-individual variability in repeated exertions) of 3.5 for all subjects in overhead lifts and 6.9 in lifts to knuckle height. The same study showed somewhat higher variability in tests of isometric strength (coefficient of variations ranging from 11.6 to 15.4). Test-retest reliability was not reported by McDaniel et al. (1983).

8.5.3.3 Is It Practical?

Isoinertial techniques generally appear practical in terms of providing a test procedure that requires minimal administration time and minimal time for instruction and learning. Even in a worst-case scenario, the isoinertial procedures used by Kroemer (1983) would take only a few minutes to determine the maximal weight lifting capability of the subject for a particular condition. The McDaniel et al. (1983) procedure can be performed in approximately 3–5 minutes.

Practicality is determined in part by cost of the equipment required, and on this account, the cost of isoinertial techniques is quite modest. The equipment needed to develop the LIFTEST devices used by McDaniel et al. (1983) and Kroemer (1982) would not be prohibitive for most applications. In fact, Kroemer (1983) states that the device is easily dismantled and could easily be transported to different sites in a small truck or station wagon, or perhaps in a mobile laboratory vehicle.

8.5.3.4 Is It Related to Specific Job Requirements?

Since industrial lifting tasks are performed dynamically, isoinertial strength tests do appear to provide some useful information related to an individual's ability to cope with the dynamic demands of industrial lifting. McDaniel (1994) reported that these tests are predictive of performance on a wide range of dynamic tasks, including asymmetric tasks, carrying, and pushing tasks. Furthermore, Jiang et al. (1986) demonstrated that the isoinertial lifting test to 6 feet was more highly correlated with psychophysical tests of lifting than isometric tests.

8.5.3.5 Does It Predict Risk of Future Injury or Illness?

The ability of a strength test to predict risk of future injury or illness is dependent upon performance of prospective epidemiological studies. As of this writing, no such studies have been conducted on the isoinertial techniques described above.

8.6 Psychophysical Strength

According to contemporary psychophysical theory, the relationship between the strength of a perceived sensation (*S*) and the intensity of a physical stimulus (*I*) is best expressed by a power relationship (Stevens, 1957).

$$S = kI^{n} \tag{1}$$

This psychophysical principle has been applied to many practical problems, including the development of scales or guidelines for effective temperature, loudness, brightness, and ratings of perceived exertion. Based on the results of a number of experiments using a variety of scaling methods and a number of different muscle groups, the pooled estimate of the exponent for muscular effort and force is 1.7 (Jones, 1986).

When applying this principle to work situations, it is assumed that individuals are capable and willing to consistently identify a specified level of perceived sensation (*S*). For manual materials-handling tasks, this specified level is usually the *maximum acceptable weight* or *maximum acceptable force*. The meaning of these phrases are defined by the instructions given to the test subject (Snook, 1985a):

> You are to work on an incentive basis, working as hard as you can without straining yourself, or becoming unusually tired, weakened, overheated, or out of breath.

If the task involves *lifting*, the experiment measures the maximum acceptable weight of lift. Similarly, there are maximum acceptable weights for *lowering* and *carrying*. Such tests are isoinertial in nature; however, in contrast to the tests described above, they are typically used to test submaximal, repetitive handling capabilities. Data are also available for *pushing* and *pulling*. These are reported as maximum acceptable forces and include data for initial as well as sustained pulling or pushing.

8.6.1 Why Use Psychophysical Methods?

Snook identified several advantages and disadvantages to using psychophysical methods for determining maximum acceptable weights (Snook, 1985b). The advantages include:

1. The method is a realistic simulation of industrial work (face validity).
2. It is possible to study intermittent tasks (physiological steady state not required).
3. The results are consistent with the industrial engineering concept of "a fair day's work for a fair day's pay."
4. The results are reproducible.
5. The results appear to be related to low back pain (content validity).

Disadvantages include:

1. The tests are performed in a laboratory.
2. It is a subjective method that relies on self-reporting by the subject.
3. The results for very high frequency tasks may exceed recommendations for energy expenditure.
4. The results are insensitive to bending and twisting.

In terms of the application of the data derived from these studies, Liberty Mutual preferred to use it to design a job to fit the worker, since this application represented a more permanent engineering solution to the problem of low back pain in industry (Snook, 1978). This approach not only reduces the worker's exposure to potential low back pain risk factors, but also reduces liability associated with worker selection (Snook, 1978).

8.6.2 Published Data

8.6.2.1 Liberty Mutual

Snook and Ciriello at the Liberty Mutual Insurance Company have published the most comprehensive tables for this type of strength assessment (Snook and Ciriello, 1991). The most recent data is summarized in nine tables, organized as follows (Snook and Ciriello, 1991):

1. Maximum acceptable weight of lift for males
2. Maximum acceptable weight of lift for females
3. Maximum acceptable weight of lower for males
4. Maximum acceptable weight of lower for females
5. Maximum acceptable forces of push for males (initial and sustained)
6. Maximum acceptable forces of push for females (initial and sustained)
7. Maximum acceptable forces of pull for males (initial and sustained)
8. Maximum acceptable forces of pull for females (initial and sustained)
9. Maximum acceptable weight of carry (males and females)

8.6.2.2 Other Sources

Ayoub et al. (1978) and Mital (1984) have also published tables for maximum acceptable weights of lift. Even though their tables are similar in format and generally in agreement with those from Liberty Mutual, there are some differences. Possible sources for these differences may be differences in test protocol, differences in task variables, and differences in subject populations and their characteristics.

8.6.3 Experimental Procedures and Methods

For the sake of simplicity and convenience, the Liberty Mutual protocol for lifting or lowering and an excerpt from the lifting table will be used as examples for this section. The protocols used by Ayoub et al. (1978) and Mital (1984) were similar, but not exactly the same. The reader should refer to the original publications for details.

The Liberty Mutual experimental procedures and methods were succinctly reviewed in their most recent revision of the tables (Snook and Ciriello, 1991). The data reported in these revised tables reflect results from 119 second-shift workers from local industry (68 males, 51 females). All were prescreened to ensure good health prior to participation. These subjects were employed by Liberty Mutual for the duration of the project (usually 10 weeks). All received 4 to 5 days of conditioning and training prior to participation in actual test sessions.

Test subjects wore standardized clothing and shoes. The experiments were performed in an environmental chamber maintained at 21°C (dry bulb) and 45% relative humidity.

Forty-one anthropometric variables were recorded for each subject, including several isometric strengths and aerobic capacity.

A single test session lasted approximately 4 hours and consisted of 5 different tasks. Each task session lasted 40 minutes, followed by 10 minutes rest. Most subjects participated in at least two test sessions per week for 10 weeks. In general, a subject's heart rate and oxygen consumption were monitored during the sessions.

8.6.3.1 Lifting or Lowering Tasks

In a lifting or lowering task session, the subject was given control of one variable, usually the weight of the box. The other task variables would be specified by the experimental protocol. These variables include:

1. *Lifting zone* refers to whether the lift occurs between floor level to knuckle height (low), knuckle height to shoulder height (center), or shoulder height to arm reach (high).
2. *Vertical distance of lift* refers to the vertical height of the lift within one of these lifting zones. The specified values for distance of lift in the tables are 25 cm (10 in), 51 cm (20 in), and 76 cm (30 in). It is possible to use linear extrapolation for lift distances not exactly equal to one of these values.
3. *Box width* refers to the dimension of the box away from the body. The three values of box width are 34 cm (13.4 in), 49 cm (19.3 in), and 75 cm (29.5 in). It is possible to use linear extrapolation between these values.
4. The final task variable is *frequency of lift*. The frequencies are expressed as one lift per time interval and include intervals of 5 seconds, 9 seconds, 14 seconds, 1 minute, 2 minutes, 5 minutes, and 8 hours.

These same definitions apply to a lowering task, except the word "lower" is substituted for "lift." The test protocol for lowering was essentially identical to that for lifting, and the results are reported in a similar format. It should be noted, however, that the test protocols for lifting and lowering involved using a special apparatus that returned the box to its original specified location, so that the subject *only* lifted or lowered, not both.

Per the instructions, the subject was to adjust the weight of the box, according to his or her own perceptions of effort or fatigue, by adding or removing steel shot or welding rods from a box. The box had handles and a false bottom to eliminate visual cues. Each task experiment was broken into two segments, so that the initial weight of the box could be randomly varied between high vs. low, so that the subject approached his or her maximum acceptable weight from above as well as below. If the results met a 15% test-retest criterion, the reported result was the average of these two values. If the results did not meet this criterion, they were discarded and the test repeated at a later time.

In reporting the results, it was assumed that the gender-specific maximum acceptable weights for a particular task were normally distributed. As a consequence, the results were reported as percentages of population, stratified by gender. The Liberty Mutual tables are organized around the following percentages: 90, 75, 50, 25, and 10% (Snook and Ciriello, 1991). The 90th percentile refers to a value of weight that 90% of individuals of that gender would consider a maximum acceptable weight (90% "acceptable"), while the 10th percentile refers to a value of weight that only 10% of individuals of that gender would find acceptable (10% "acceptable").

8.6.3.2 Important Caveats

Snook and Ciriello (1991) have identified several important caveats that should be remembered when using the Liberty Mutual tables.

1. The data for each experimental situation were assumed to be normally distributed when the maximum acceptable weights and forces acceptable to 10, 25, 50, 75, and 90% of the industrial population were determined.
2. Not all values in the tables are based on experimental data. Some values were derived by assuming that the variation noted for a particular variable for one type of task would be similar to that observed for another task (e.g., the effects on lowering would be similar to that on lifting).
3. The tables for lifting, lowering, and carrying are based on boxes with handles that were handled close to the body. They recommend that the values in the tables be reduced by approximately 15% when handling boxes without handles. When handling smaller boxes with extended reaches between knee and shoulder heights, they recommend reducing the values by approximately 50%.
4. Some of the reported weights and forces exceed recommended levels of energy expenditure if performed for 8 or more hours per day. These data are italicized in the tables.
5. The data in the tables give results for individual manual materials-handling tasks. When a job involves a combination of these tasks, each component should be analyzed separately, and the component with the lowest percent of capable population represents the maximum acceptable weight or force for the combined task. It should be recognized, however, that the energy expenditure for the combined task will be greater than that for the individual components.

Some recent data suggest that persons performing lifting tasks are relatively insensitive to the perception of high disk compression forces on the spine (Thompson and Chaffin, 1993). As a result, there may be some tasks in the tables that exceed recommended levels of disk compression.

8.6.4 Related Research

8.6.4.1 Task and Subject Variables

A variety of researchers have examined the effects of other task and subject variables using the psychophysical protocol. Most of these studies involve a small number (<10) of college students as test subjects. Some experiments used the Liberty Mutual protocol; others used the protocol described by Ayoub et al. (1978) and Mital (1984). These "refinements" are summarized in Table 8.3.

8.6.5 Recommended Applications

8.6.5.1 Job Evaluation

The Liberty Mutual tables were developed for the purpose of evaluating work, not workers (Snook, 1987). In particular, the tables are intended to help industry in the evaluation and design of manual materials-handling tasks that are consistent with worker limitations and abilities (Snook and Ciriello, 1991). The explicit goal is the control of low back pain through reductions in initial episodes, length of disability, and recurrences (Snook, 1987).

TABLE 8.3

Miscellaneous Task Variables Evaluated Using the Psychophysical Methodology

Task Variable(s)	Reference(s)
Zone of lift	Snook, 1985a
Distance of lift	Snook and Ciriello, 1991
Frequency of lift	Ayoub et al., 1978
Box width	Mital, 1984b
	Ciriello and Snook, 1983
	Mital and Ayoub, 1981
	Asfour et al., 1984
	Garg et al., 1980
Extended work shifts	Mital, 1984a
Combinations of lift, carry, and lower	Ciriello et al., 1990
	Jiang et al., 1986b
Angle of twist	Asfour et al., 1984
Box length	Asfour et al., 1984
	Garg et al., 1980
Material density	Mital and Manivasagan, 1983
Location of center of gravity	
Center of gravity relative to preferred hand	
Sleep deprivation	Legg and Haslam, 1984
Bag versus box	
Fullness of bag (same weight)	
Bag ± handles	
Day 1-to-day 5 of work week	Legg and Myles, 1985
Asymmetrical loads	Mital and Fard, 1986
Asymmetrical lifting	Mital, 1987a
	Mital, 1992
	Drury et al., 1989
Emergency scenario	Legg and Pateman, 1985
Handle position	Drury and Deeb, 1986
Handle angle	
Duration of lifting	Mital, 1984a
	Fernandez et al., 1991
Overreach heights	Mital and Aghazadeh, 1987
Restricted vs. unrestricted shelf opening clearances	Mital and Wang, 1989
Experienced vs. inexperienced workers	Mital, 1987b
Non-standard or restricted postures	Gallagher et al., 1988
	Gallagher, 1991
	Gallagher and Hamrick, 1992
	Smith et al., 1992

To apply the tables in the context of job evaluation, it is first necessary to specify the task variables of the job. For a lifting task, this would include the lift zone, distance of lift, box width, frequency of lift, and the presence or absence of box handles. In addition, it would be necessary to measure the weight of the object to be handled, perhaps using a scale or dynamometer. Once these variables are specified, the measured weight can be compared to the data in the table to determine the percent of capable population for males and females. The procedure is similar for pulling or pushing. The required force can be measured with a dynamometer.

Consider the following example. The task is to lift a 49-cm wide box that weighs 20 kg, once every minute, from floor level to knuckle height for a distance of 51 cm. Referencing Table 8.4, an excerpt from the Liberty Mutual tables, it is seen that the weight of the box, 20 kg, is exactly equal to the maximum acceptable weight of lift for 75% of males (i.e.,

TABLE 8.4

Excerpt from the Liberty Mutual Tables for Maximum Acceptable Weight of Lift (kg) for Males and Females

				Floor Level to Knuckle Height One Lift Every							
Gender	**Box Width (cm)**	**Distance of Lift (cm)**	**Percent Capable**	**5 sec**	**9 sec**	**14 sec**	**1 min**	**2 min**	**5 min**	**30 min**	**8 h**
			90	7	9	10	14	16	17	18	20
			75	10	13	15	20	23	25	25	30
Males	49	51	50	*14*	17	20	27	30	33	34	40
			25	*18*	*21*	25	34	38	42	43	50
			10	*21*	*25*	*29*	40	45	49	50	59
			90	*6*	7	8	9	10	10	11	15
			75	*7*	9	9	11	12	12	14	18
Females	49	51	50	*9*	10	11	13	15	15	16	22
			25	*10*	*12*	13	16	17	17	19	26
			10	*11*	*14*	15	18	19	20	22	30

Note: Italicized values exceed 8-hour physiological criteria (energy expenditure).

75% of males would consider this task "acceptable"). By contrast, the highest maximum acceptable weight of lift reported for females is 18 kg. As a result, this task is "not acceptable" to over 90% of females.

8.6.5.2 Job Design

To apply the tables in the context of job design, the process is essentially identical. All task-specific parameters must be identified, except the required weight or force (that is what you are determining). You select a desired percent of capable of population, noting gender effects, and then identify the maximum acceptable weight or force that corresponds to that desired percent. This is the value recommended for job design.

As an example, suppose you wish to design a lifting task that requires a 49-cm wide box that must be lifted 51 cm once per minute within the floor-to-knuckle zone. You desire to design this job to accommodate 75% of females. According to the data in Table 8.4, you would recommend that the box weigh no more than 11 kg. This weight would be acceptable to 75% of females and over 90% of males.

Multiple task analysis, consisting of a lift, carry, and lower, has also been investigated for the Liberty Mutual data (Ciriello et al, 1990). In this circumstance, it was observed that the maximum acceptable weight for the multiple task was lower than that for only the carrying task when performed separately, but not significantly different from the lifting or lowering maximum acceptable weights when performed separately. For this type of a multiple task, the maximum acceptable weight for the task should be the lowest maximum acceptable weight of the lift or lower as if it were performed separately. One should be careful, however, because the energy expenditure for the multiple task is probably underestimated when compared to performing the tasks separately. Similar results were reported by Jiang et al. (1986).

8.6.6 Evaluation According to Criteria for Physical Assessment

8.6.6.1 Is It Safe to Administer?

According to Snook (1992), there has been one compensable injury among the 119 industrial worker test subjects. This single episode involved a chest wall strain associated with a high lift. It was also associated with four days restricted activity, but no permanent disability.

8.6.6.2 Does the Protocol Give Reliable Quantitative Values?

The Liberty Mutual protocol incorporates a criterion for test-retest reliability (maximum difference of 15%). Legg and Myles (1985) reported that 34% of their data did not meet this criterion. In contrast, Gallagher (1991) reported that only 3% of tests in their study had to be repeated because of violating the 15% test-retest criterion. Clearly, the maximum acceptable weights and forces are quantitative.

8.6.6.3 Is It Practical?

There are two major sources of impracticality associated with this type of strength assessment: (1) it is conducted in a laboratory, and (2) the duration of testing is somewhat prolonged compared to other strength assessment methods. It is possible, however, to have the subjects use objects that are actually handled in the workplace. Equipment is not very costly.

8.6.6.4 Is It Related to Specific Job Requirements (Content Validity)?

The content validity of this method of strength assessment is one of its greatest assets. One potential weakness, however, is its insensitivity to bending and twisting.

8.6.6.5 Does It Predict Risk of Future Injury or Illness (Predictive Validity)?

The results of two epidemiological studies suggest that selected indices derived from the psychophysical data are predictive of risk for contact injury, musculoskeletal disorders (excluding the back), and back disorders (Ayoub et al., 1983; Snook et al., 1978). These indices are correlated to the severity of these injuries. A third study demonstrated predictive value (Herrin et al., 1986). It should be noted, however, that at high frequencies, test subjects selected weights and forces that often exceeded consensus criteria for acceptable levels of energy expenditure. In addition, test subjects may also select weights and forces that exceed consensus levels of acceptable disk compression.

8.7 Summary

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 large differences in strength, not only between individuals, but even within the same individual tested repeatedly on a given piece of equipment. The issue is compounded by the fact that correlations of strength among different muscle groups in the same individual are generally low, and that tests of isometric strength do not necessarily reflect the strength an individual might exhibit in a dynamic test. As a result of these and other influences, it is evident that great care needs to be exercised in the design, evaluation, reporting, and interpretation of muscular strength assessments.

Traditionally, tests of muscular strength were in the domain of the orthopedist, physical therapist, and exercise physiologist. However, such tests are also an important tool for the ergonomist, due to the high-strength demands required of workers in manual materials-handling tasks. In some cases, it has been shown that task demands may approach or even exceed the strength that an individual is voluntarily willing to exert in a test of strength. In such cases, there is evidence to suggest that the likelihood of injury is significantly greater than when the task demands lie well within an individual's strength capacity. Because the relationship between strength capabilities, job demands, and musculoskeletal injury has been established, it becomes apparent that tests of muscular strength may be of benefit to the ergonomist, both in the design of jobs and in ensuring that individuals have sufficient strength to safely perform physically demanding jobs. Several different strength assessment techniques have been employed for these purposes, each possessing unique characteristics and applicability to job design and/or worker selection procedures. The main purpose of this chapter has been to elucidate the strengths and weaknesses of some of these procedures, so that tests of strength may be properly applied in the design of jobs and the selection of workers.

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