2. Isometric Strength

Definition of 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 no body movement occurs during the measurement period. The tested person's body angles and posture remain the same throughout the test.

Isometric strength has historically been the type most studied and measured. It is probably the easiest to measure and 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 (each moves in his or her unique manner and 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. Both researchers and users should collect and use data that they understand and that fits their application.

Workplace Assessment

When a worker is called on to perform a physically demanding lifting task, the external load produces moments — tendencies to produce motion, also called torques — about various joints of the body.(1) 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 forearm's center of mass. To perform the task successfully, the muscles responsible for moving the joint must develop a greater moment than the combined moments of the external load and body segment. It should be clear that, at each joint of the body, there is a limit to the strength that the muscle can produce to move ever-increasing external loads. This concept forms the basis of isometric muscle strength prediction modeling.(1)

The following procedures are generally used with this biomechanical analysis technique. First, workers are observed (and usually photographed or videotaped) as they perform 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 as the task is performed. 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 estimates the proportion of the population capable of performing the exertion, as well as the predicted compression forces acting on the lumbar discs as a result of the task.

Figure 2 shows an example of the workplace analysis necessary for this approach. Direct observations of the worker performing the task provide the necessary data. For example, one must know the load magnitude and direction (in this case, a 200 N load acting downward), 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 to perform it. Results of this particular analysis indicate that the muscles at the hip are most stressed; 83% of men but only slightly more than 50% of women would have the necessary strength in this region. These results can then be used as the basis for determining which workers have adequate strength for the job. However, such results can also be used as ammunition for recommending changes in job design.(1)

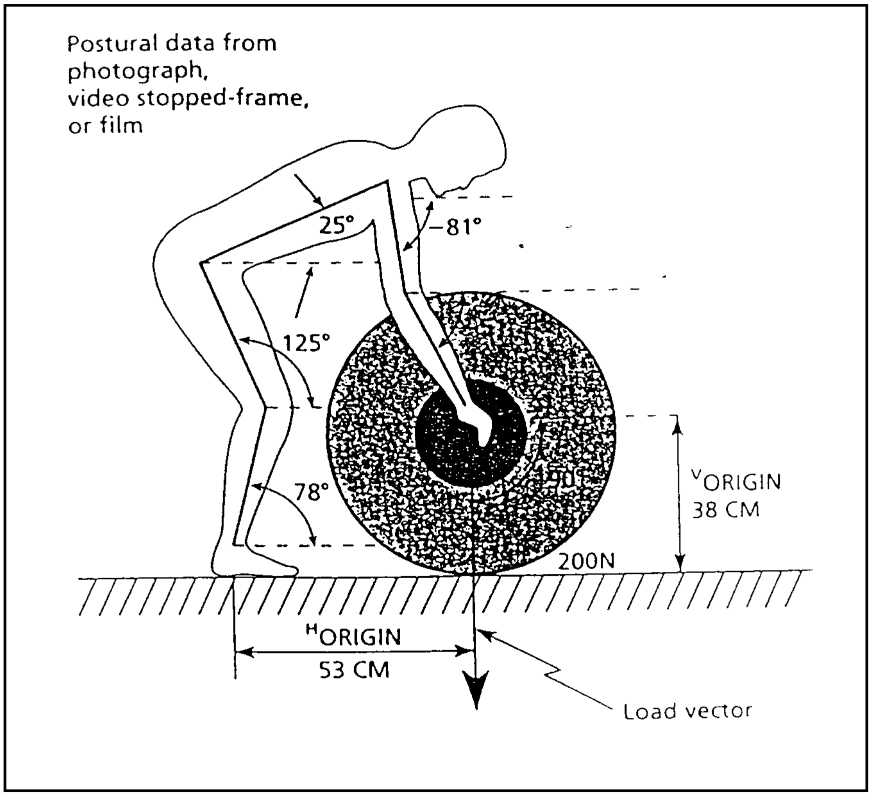

Figure 2*—Postural data required for analysis of joint moment strengths using the isometric technique.* (From *Occupational Biomechanics,* Chaffin, D.B., and G.B.J. Andersson, ©1991 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

Isometric Testing Protocol

The basic protocol for isometric strength testing was developed by Caldwell et al.[2] and published in an AIHA ergonomics guide by Chaffin.[3] The protocol outlined herein includes additional information determined by researchers since that time. When conducting isometric testing, a number of factors must be considered and controlled (if possible) to avoid biased results. These factors include:

- Equipment used to make the measurements;
- Instructions given to the person tested;
- Duration of the measurement period;
- Person's posture during the test;
- Length of the rest plod between trials;
- Number of trials a person is given for each test;
- Tested person's physical state at the time of testing;
- Type of postural control used during the tests; and
- Environmental conditions during the test.

Test Duration

The length of an isometric strength test impacts the result in two ways. If it is too long, the subject will fatigue and the strength score will decline. If it is too short, the subject will not reach his or her maximum force level before the test is terminated. Chaffin suggests a 4-second test, with the score being the average strength displayed during the second through fourth seconds.[3] The appropriate 3-second period is determined as follows:

If the measuring equipment has the capability, collect strength data by having the person begin contraction with the equipment, monitor the force until some preselected threshold is reached (usually 20%–30% below the expected maximum force for the person and postures, have equipment wait 1 second, and then have the equipment average the displayed force for the next 3 seconds. This is easily done with computerized systems.

If the equipment does not have this capability, have the person tested begin the test and gradually increase his or her force over a 1-second period. The force should be measured and averaged over the next 3 seconds. In complex whole body tests involving multiple functional muscle groups, persons may take a few seconds to reach their maximum. Under these conditions, the data collector must adjust the premeasurement time interval accordingly and carefully monitor the progress of the testing to ensure that the maximal force during the 3-second period is, in fact, being measured.

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 may reveal feelings about the testee or the desired outcome 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 (e.g., "pull, pull, pull, you can do it"), spectators, between-person competition, and unusual noises 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 when the test is complete. Quantitative results provided during the testing period may change the person's incentive and thus the test result.

To the tested person, a 4-second maximal exertion seems to take a long time. During the test, tester–testee agreed-on feedback, such as a slow 4 count, should be provided so the tested person knows how much longer a test will last.

Rest Period Length

Persons undergoing isometric strength testing generally perform a series of tests, with a number of trials for each test. Under these conditions, localized muscle fatigue must be avoided since it will result in underestimating strength. Studies by Schanne(4) and Stobbe(5) have shown that a minimum rest period of 2 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.

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 with either isometric testing or forceful physical exertion in general. In addition, these people often require a series of test trials to reach their maximum. The use of a single trial of a test generally underestimates a person's maximum strength, possibly by more than 50%. A 2-trial protocol results in less of an underestimate, but it may still exceed 30%.[6]

For this reason, it is preferable to determine the number of trials for each test based on performance. Begin by having the subject perform two trials of the test. Compare the two scores, and if they are within 10% of each other, use the highest of the two values as the estimate of the person's maximal strength, then proceed to the next test. If the two values differ by more than 10%, perform additional trials of the same test until the two largest values are within 10% of each other. Using this approach, Stobbe and Plummer averaged 2.43 trials per test across 67 subjects performing an average of 30 different strength tests.[6] In any case, a minimum of two trials is needed for each test.

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. In the absence of specific muscle strength training, however, 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 varies from person to person and depends 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.

Test Posture

Measured strength is highly posture dependent. Even small changes in the body angles of persons being tested 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 are sought, and then design one or more strength tests to provide that specific type of data. If, for example, the test is 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 ensure that the same posture is used on each trial of the test, monitoring the test to ensure that the 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.

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 (Figure 3). In addition, restraint systems help ensure that all persons participating in a given study are performing the same test. The type and 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, either of which will impact test results.

Any restraint system used should be comfortable and 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. Achieving the latter condition often requires some experimentation.

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

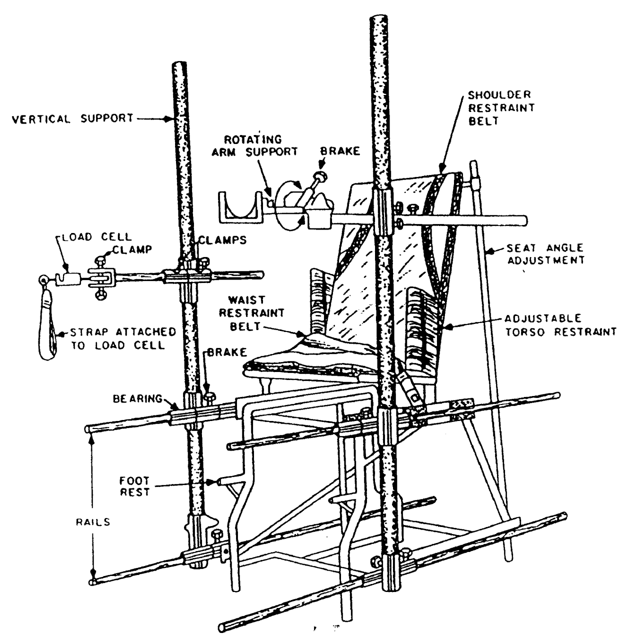

Figure 3*—Example of a test fixture designed to restrain various body segments during isometric strength testing.* (From *Occupational Biomechanics,* Chaffin, D.B, and G.B.J. Andersson, ©1991 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)

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 are acceptable. In cases where the effects of the environment on measured strength or physical performance must be determined, appropriate conditions can be established (e.g., work sites requiring exposure to hot or cold temperature extremes).

Equipment

Isometric strength testing equipment has not been standardized. Any equipment capable of performing the necessary timing and averaging described previously 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-D converter and managed by appropriate software or complex multiple-mode strength measuring devices manufactured by companies such as Cybex, Chattex, Loredan, and Isotechnologies. Prices vary from $1000 plus to as high as $50,000 or $100,000.

The issue is not equipment price, rather, it is equipment function. Researchers should select or build equipment suited to their needs. Researchers must also understand what is happening inside the device (and its associated software) in order to properly interpret the data they collect.

The human–equipment interface is another matter that affects 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 generally provide a maximal exertion in a situation in which 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.

Subjects

The subjects selected for strength testing will determine the results obtained. When collecting strength data, the subjects selected must therefore appropriately represent the population the test claims to describe (e.g., 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. Other medical conditions, including hypertension, 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:

- Gender;
- Age distribution;
- Relevant anthropometry (height, weight, etc.);
- Sample size;
- Method by which sample was selected and who it is intended to represent;
- Extent of strength training done by participants, and their experience with isometric testing; and
- Health status of participants (medical exam and/or health questionnaire recommended).

Strength Data Reporting

Following are the minimum data that should be reported for strength testing projects:

- Mean, median, and mode of data set;
- Standard deviation of data set;
- Skewness of data set (or histogram describing data set); and
- Minimum and maximum values.

Evaluation According to Physical Assessment Criteria

A set of five criteria has been proposed to evaluate the utility of all forms of strength testing. isometric strength testing is evaluated with respect to these criteria in the following sections.

Is Isometric Strength Testing Safe to Administer?

Any form of physical exertion carries some risk. The directions for the person undergoing an isometric test specifically state that the person is to slowly increase the force until he or she reaches what feels like a maximum, and to stop any time during the exertion if discomfort or pain is experienced. The directions also expressly forbid jerking on the equipment. Isometric testing performed in this manner is quite safe to administer because the tested person decides 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 rare reports of some residual soreness in the muscles that were active in the test(s).

Does Isometric Strength Testing Provide Reliable Quantitative Values?

The test–retest variability for isometric testing is 5%–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 these factors, and that test postures are properly controlled, isometric strength testing is highly reliable and quantitative.

Is Isometric Strength Testing Method Practical?

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

Is Isometric Strength Testing 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 lose both content- and criterion-related validity as job demands become more dynamic.

Does Isometric Strength Testing 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.[7,8] The accuracy of this prediction depends on the quality of the job evaluation on which the strength tests are based and the care with which the tests are administered.

Summary

Isometric strength is defined as the capacity to produce force or torque with a voluntary isometric (muscles maintain a constant length) contraction. A characteristic of this type of strength measurement is the absence of body movement during the measurement period. Isometric strength testing has a long history, and it may be the easiest to measure and understand. The basic procedures for testing isometric strength are well-established. Risk of injury appears to be small, and of relatively minor nature. Residual soreness of muscle groups tested is occasionally reported. Tests of isometric strength appear reliable, with test–retest variability on the order of 5%–10%. The approach appears quite practical and has been applied in many industrial situations. The major limitation of isometric strength testing is in its inability to accurately model materials handling tasks that have a significant dynamic component. It is therefore recommended that tests of isometric strength be applied when there is little or no dynamic movement involved. In spite of this limitation, it should be duly noted that of all the procedures reviewed in this chapter, tests of isometric strength are the only strength tests that have shown the ability to predict individuals with a high risk of future injury or illness on physically stressful jobs.[1] The accuracy of this prediction appears to depend on careful biomechanical evaluations of the jobs on which strength tests are based, and proper administration of the isometric strength testing procedures.

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