Philosophy of the Ergometric Strength Testing

It has been determined that the majority of work related physical impairments in this country are due to the loss of strength in either limb or lower back. Therefore, the measure of one's residual strength is essential to determining the extent of physical impairment.

Several quotes from the "Work Practices Guide for Manual lifting 1981" published by the U. S. Department of Health and Human Services read as follows:

"Due to the lack of consensus on methodology, an ad hoc committee of experts first held a series of meetings in 1972 for the purpose of proposing a strength testing standard (Caldwell, et al., 1974). The recommendations of this group were later adopted as an "Ergonomics Guide for the Assessment of Human Static Strength" by the American Industrial Hygiene Association (Chaffin 1975). This guide describes the use of static tests for the measurement of human strength.

Static strength is defined as:

> "...the maximal force muscles can exert isometrically in a single voluntary effort." (Roebuck, Kroemer, and Thompson, 1975)

There are several advantages in using this technique of strength assessment.

1. The technique is relatively simple.

2. Subjects are at minimal risk of injuring themselves during this type of test since the exertion is isometric and completely voluntary. They are requested to slowly increase their exertions, and to stop if any abnormal discomfort is felt.

3. The measurement is repeatable with a high degree of reliability.

Criteria for Physical Assessments

There are many different methods by which a concerned physician may evaluate a person's capability to handle heavy loads safely in a future job. Some of these methods may have merit. Others are of questionable value. In providing any such assessment it is important that certain medical, social, economic, and legal criteria must be met. In choosing between alternative methods, it is suggested that the following criteria be applied:

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? "

"Isometric strength tests are preferred due to the safety criterion. In an isometric test the subject is required to slowly increase the force exerted until they reach a level which "feels" safe. No specific feedback or challenges are given during the testing. This procedure has been proposed in an AIHA Ergonomic Guide as being a safe and reliable procedure (Chaffin, 1975). It has been used in a number of industrial studies (See Chapter 5) testing over 3000 individuals and no injuries have been reported with the above procedure.

As to whether such testing is a valid indicator of potential risk of future injury, two longitudinal studies have been performed. Collectively, these have involved nearly 1000 workers in both a light and heavy products industries (Chaffin, 1974; Chaffin, et al., 1978). These studies have revealed that both frequency and severity rates of musculoskeletal problems were about three times greater for those workers who placed on jobs that required physical exertions above that demonstrated by them in the isometric strength test, when compared with workers placed on jobs having exertion requirements well below their demonstrated capabilities."

It has been determined by the experts researching muscle physiology, psychophysical principles, biomechanics, and job design, that isometric strength tests simulating work tasks are the best measures as to whether or not a person has the strength to perform a particular job.

Biomechanical Modeling - The Common Link

The objective of an effective strength testing program is to reduce the incidence and severity of overexertion injuries. Accomplishment of this objective involves analyses of two interacting components, the worker and the workplace. The techniques utilized to document and analyze physical work requirements and the physical abilities of the worker should share a common scientific basis. Biomechanical strength modeling provides one common basis. Such models compare the physical stresses generated in the body (due to job defined variables) with the resultant force)or volitional strength) capabilities of industrial work populations. This translation of job stresses into human ability terms is the common link necessary for an effective system for engineering job redesign and personnel selection.

One biomechanical strength model available today was developed at the The University of Michigan's Center for Ergonomics. This model is fully documented elsewhere (Chaffin, 1969; Schanne, 1973; Garg, 1973; Garg and Chaffin, 1975). The following brief description of the model describes the more functional aspects.

The biomechanical strength model considers the body to be a system of rigid links and joints. Essentially, the model operates by first computing required torques at each joint center for a given task. These required torques are a function of:

1) the external forces acting on the body, (e.g. the weight of the object)

2) the position of the hands with respect to the feet, and

3) the body posture maintained while performing the task.

Data describing external forces, hand locations, and body postures are measured during a biomechanical job analysis and serve as input to the model.

Once the model has computed the required torques at each joint center, the next step is to compare these values to volitional torques (i.e., muscular strengths) which can be produced at each joint. Volitional torque data have been compiled from laboratory experiments and field strength testing of over 3,000 workers throughout the United States. For a specified population and body posture, the model computes a volitional torque capability distribution for each joint. The required torque at the joint is then compared to this distribution in order to statistically estimate the fraction of the population capable of producing the torque. This estimation procedure is repeated at each joint center. The joint with the smallest population fraction is defined to be the limiting muscle strength and determines the percentage of the population that can successfully perform the task. These volitional torque distributions can be stratified for male and female populations as well as older versus younger work forces.

In summary, a biomechanical strength analysis produces three key pieces of information.

1. It rank orders the gross strength requirements of the various tasks involved in a job.

2. It identifies the muscle group which limits performance on each task.

3. It predicts the percentage of the male and female working populations that could be expected to perform each job activity.

The Validity of Biomechanical Modeling as a Predictor of Human Muscular Strength

The predictive accuracy of the biomechanical strength model at the Center for Ergonomics continues to improve as additional strength data become available for extreme postures. Validation studies examine the simple relationship between predicted and measured hand forces as follows:

$$Fp = B\ Fm$$

where: Fp = Model predicted hand force
Fm = Measured hand forces
B = Slope of least-squared error regressional line.

Where B = 1 would indicate unbiased prediction. Early validation studies (Garg and Chaffin, 1975) yielded B in the range of .82 - .87 within a coefficient of determination (R2) of approximately .75 and an error coefficient of variation of approximately 15% which agreed with earlier research efforts (Chaffin and Baker, 1970; Schanne, 1972). These early validation studies were based on comparison of predicted strength with existing military strength data from the literature. The early studies resulted in the recognition that to improve the predictive accuracy of the model a larger data base of industrial worker strengths was needed.

Based upon a study of 1577 industrial workers involving eight different U.S. companies, the predictive accuracy of the model was much improved (Frievalds, 1980). The slope of the regression between predicted and measured mean strengths was nearly perfect (B = .99) with and R2 of .83 with a high significance level ($p < .001$).

Methods Used in the Ergometric Strength Test

The subject was asked to thoroughly describe his/her job. The various postures, Horizontal(H) and Vertical (V) distances of load and the weight of the load were recorded. This information was then verified with the employer.

The most stressful postures in the subjects work were selected and tested ergometrically.

Patient Instructions

1. The subject was asked to sign a consent form prior to testing.
2. The subject was asked to stand in front of the handles so that the ankle of the forward foot was the same horizontal distance from the handles as the horizontal distance determined during the biomechanical analysis.
3. The subject was asked to grasp the handles and to pull as hard as he/she desired to gain confidence that they were secure, and could support a maximal effort. The subject was asked again at this time if there were any questions regarding the test procedures. Also, the subject was asked to select a posture which would allow him/her to produce maximum strength reminding him/her that the position of the forward foot could not be shifted.
4. Once the subject was confident of a good posture, the following instructions were read:

   "Slowly pull (push) on the handles until you reach what you believe to be a maximum exertion. This exertion should be what you believe you are capable of doing if given a heavy object to handle in your job. If you feel any abnormal discomfort while increasing the forces on the handles, stop increasing that force at that level."

5. The subject was allowed to rest <u>at least two minutes between trials</u>. Additional rest was given at the request of the employee. Normally, a maximum of four minutes rest is quite adequate between trials.

Preceding each different type of test, the worker was allowed to practice the required exertions to assure uniformity with instructions, and to gain confidence.

Each test lasted 5 seconds in duration and each position was tested 3 times. The peak forces exerted were recorded using a digital recorder which averaged the maximum exertion over a 3-second interval. The exerted force was also recorded graphically using a Strip Chart Recorder. The bell-shaped curves produced by the recorder were compared in each set of trials for reproducibility.

An important consideration in any strength test is whether or not there is a volitional element that would cause discrepancy in the results such as to discredit the maximum effort made in the tests. The volitional element was detectable by the shape of the power-force curve seen on the strip chart analog recording. In a repetition of static test, duplicating the variables exactly from test to test should be of the same peak and average values and the curves should appear duplicates of each other. If there is a volitional alteration of the test in such a way as to not approximate maximum, the curves will vary and this is easily detectable. The results from volitionally manipulated tests are deleted from the analysis.

Photographs of the subject were taken in each position, and the results of each test were recorded on a data sheet, with the graph paper displaying the bell-shaped curves, attached behind.

INPUT

The information on the data sheets (one for each position) were inputted into the Biomechanical Model computer model.

Output of the Model included:

A. A restatement of input information.

B. Percentage of population capable of exerting sufficient isometric strength to successfully perform any job element.

C. The muscle group which is most limiting to the person performing the exertion (weakest link).

D. A comparison of the subject's weakest link to that of 75% of the population.

Any task for which 75% or more of the normal population can perform without difficulty would be considered and acceptable job for a normal individual. A task that could be accomplished only by 25% or less of the normal population would not be considered acceptable for the average normal worker. The multitude of variations of various postures with various H and V measurements have been programmed into the Biomechanical Computer Model. It is thus possible to compare the tolerance levels for specific tasks of an individual against the normal population in the data base of the computer.