Preemployment Strength Testing
An Updated Position

Don B. Chaffin, Ph.D.; Gary D. Herrin, Ph.D.; and W. Monroe Keyserling, M.S.

This investigation was conducted to evaluate the practicality and potential effectiveness of preemployment strength testing in reducing the incidence and severity of musculoskeletal and back problems in materials handling jobs. Prior to assignment to new jobs, 551 employees in six plants were given a series of strength tests and then monitored for approximately 18 months. During this time, all medical incidents were documented. An analysis of these incidents revealed that a worker's likelihood of sustaining a back injury or musculoskeletal illness increases when job lifting requirements approach or exceed the strength capability demonstrated by the individual on an isometric simulation of the job. Because strength was found to be weakly correlated with other individual attributes (e.g., gender, age, weight, and stature), the authors conclude that industry should implement specific employee selection and placement programs using a strength performance criterion.

Earlier papers by these authors and others have supported the concept that the incidence and severity of musculoskeletal illness or injury can be reduced on jobs requiring physical exertions. It has been proposed that such a reduction can be achieved by selectively employing workers who can demonstrate strengths in standardized tests which are as great or greater than that required in the normal performance of their jobs. In the course of this type of research, many basic and practical questions have been raised. For instance: What type of strength tests are effective? How many tests must be performed? What are the risks to the prospective employee during the tests? How much strength is needed to be "protective"?

Because of these and other questions, and the obvious fact that if strength testing were to be performed for preemployment purposes, it would necessarily deny employment to proportionally more women and older employees, another longitudinal study was initiated under a NIOSH contract in 1974.

The specific objectives of this latest study were: (1) To develop and utilize a set of isometric lifting tests to predict the strength capacities that a heterogeneous group of workers can produce on their jobs; and, (2) To statistically estimate the degree and type of personal risk that exists when a person is required to perform an exertion on a job which exceeds his/her strength capacity as measured by standardized isometric strength tests administered at the initiation of the job assignment.

The first objective required the formulation of a rational strength testing program for employees assigned to jobs requiring a known amount of physical exertion, particularly exertions involving load lifting. The second objective required the systematic evaluation of employee strengths upon entering jobs having physical exertions, and then following each employee's medical status while assigned to such job.

Methods Developed for Subject Strength Testing
Several criteria were considered important in developing the type of strength testing needed in the future. First, any such procedure must be safe. This criterion precluded having people attempt to lift specific objects (e.g., bar bells, tote boxes filled with lead shot, steel bars, etc.), since to do so would expose the person to the hazards of both dropping the object on a foot and the dynamic stresses imposed by the motion imparted to the object. Based on this thinking, an isometric test was proposed. In such a
test a person simply increases the forces exerted on a set of static handles to the level felt to be his/her maximum volitional force producing capability. The handles are attached to a load cell which then measures the forces exerted and through an electronic display device allows the test supervisor to record the forces both peak and average during a given testing period. Such a testing protocol has been carefully defined by a group of researchers, and is described and advocated in several earlier papers on the subject. These should be carefully read by anyone contemplating a strength testing program.

A second criterion for in-plant employee strength testing is that the test be a "reasonable" simulation of the job strength requirements. This criterion is required by law. A major factor affecting the amount of strength a person can demonstrate is the location of the hands during the exertion (i.e., a person may be able to lift 100 pounds when held in close to the body but only 20 pounds at arms length). Because of this, any strength test must consider where the load is located relative to the person attempting to manipulate the load. For this reason it was decided to require that several strength tests be given which would simulate (1) lifting a compact object close to the floor using a leg/squat lift technique, (2) lifting a bulkier object from the floor using a back lift technique, and (3) lifting an object from a table or bench using an arm lift. These three tests will be referred to as Standard Posture Tests and are illustrated in Fig 1. This figure also includes strength distribution histograms for males and females in each of the standard posture tests.

In addition, the job that each person was assigned to was evaluated biomechanically to determine the load (hands) location of the most strength requiring lifting task. The procedure for such evaluations has been described in the earlier papers with an updated procedure described in more recent papers. These biomechanical job evaluations provided the basis for establishing a fourth strength test of each employee which replicated the hand locations found to be the most strength requiring in the job onto which he/she was being placed. This fourth test, referred to as the Job Position Test, was administered four times to each employee to estimate the repeatability of such a test in industry. By using the different postures during the testing it was believed that the criterion requiring the tests to simulate the job demands of heavy load lifting was met reasonably well.

Two practical criteria which must always be acknowledged are that any such tests be easily performed and reliable. Ease of performance is best gauged by the time required for administration. For isometric strength testing as required in this study, instructions to the employee, practice and performance of the seven tests required about 30 minutes. By reducing the number of tests, a goal of the present research program, less time would be required.
Methods for Evaluating Strength Testing Effectiveness

As mentioned before, earlier studies had indicated the potential for strength testing and placement to be effective in preventing employee injury and illness, particularly the occurrence of low-back pain. The latest study advocated the further evaluation of this concept by the following means: (1) Perform a biomechanical evaluation of jobs known to have a moderate to high degree of required lifting to identify the most strength requiring lifting task in each job. (2) As people are chosen for these jobs, have them perform both the three standard posture strength tests and the job position test which simulates the hand location required when performing the most strenuous task in the job (as identified in step 1). (3) Carefully monitor the medical status of each person entering the jobs included in the study for the length of time they are on the jobs or 18 months, whichever comes first.

In addition, a careful medical history and physical examination was performed by each participating plant physician before the employee entered the study. Also, the purpose of the study was explained with a request that he/she volunteer for such. After three weeks and at the end of their job tenure, supervisor performance ratings were obtained to provide an additional measure of effectiveness. This information was entered into a computerized Occupational Health Monitoring and Evaluation System (OHMES) which could retrieve data on individual employees or for the total study. A diagram of the data inputs and outputs of OHMES is given in Fig. 2.

Job and Worker Population Statistics

Over 900 jobs in six different plants were included in the study. All jobs chosen had at least a 35-pound equivalent weight lifting requirement, and, therefore, were considered to involve some degree of manual materials handling. During the 1-1/2 year follow-up period, 551 people were strength tested for these jobs with all resulting medical and supervision data reported for analysis. Of these people, 446 were men and 105 were women.

<table>
<thead>
<tr>
<th>Age</th>
<th>50°</th>
<th>60°</th>
<th>50°</th>
<th>60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 yrs</td>
<td>753</td>
<td>503</td>
<td>725</td>
<td>645</td>
</tr>
<tr>
<td>60 yrs</td>
<td>886</td>
<td>635</td>
<td>768</td>
<td>688</td>
</tr>
<tr>
<td>50 yrs</td>
<td>564</td>
<td>314</td>
<td>645</td>
<td>688</td>
</tr>
<tr>
<td>60 yrs</td>
<td>664</td>
<td>446</td>
<td>688</td>
<td>613</td>
</tr>
</tbody>
</table>

Table 1. — Predicted Standard Strengths for Various Cases of Stature, Body Weight, Gender and Age.
analysis of Results

Examine the predictability of a person's strength capabilities—common to industrial work—a number of analyses were performed. For the standardized postures (torso, arm, and leg length, see Fig. 1) a regression analysis revealed that the workers' age, body weight, and stature all played important roles in mining population average strengths. As shown in Table 1, strength is greatest for tall, heavy, young, male workers. Further, body weight works most to the advantage of tall workers being deleterious for older workers. Also, females do not appear to use their body weight as effectively as their male counterparts. Arm and leg strengths appear to follow this same general trend.

An important point with this analysis is that the remaining variance between lambs and within (test-retest) particular males is quite large, ranging from an average standard deviation of 7 pounds for arm strength to 67.5 pounds for leg strength. It would be imprudent to use these anthropometric values alone (without testing) to predict how any particular individual would fare on a particular strength measure.

Work postures are not reflected in the preceding three standard tests. To predict another strength posture capability, a standardized test battery a simple model was identified using most of the variability between individuals (R² = .73).

A shows a hypothetical approximation which could be applied between the standardized test scores. For job as requiring lifting of objects above elbow height we would arm strength to be the controlling criterion with the stance capability being discounted as the object is displaced further from the body (horizontally). Similarly, the adjusted leg strength would reflect objects close in to the body and low while torso strength could be used for objects both low and away from the body.

The simplest prediction equation based on this model is of the following form:

**Zone 3**

\[ \text{Job Position Strength} = 6.25 \left( \frac{\text{Arm Strength}}{\text{Horizontal Displace}} \right) \]

for horizontal displacement greater than ten inches, and

\[ \text{Job Position Strength} = \text{Arm Strength} \text{ for horizontal displacement less than or equal to ten inches.} \]

**Zones 1 or 2**

\[ \text{Job Position Strength} = 10.0 \left( \frac{\text{Leg Strength}}{\text{Horizontal Displace}} \right) \]

It is interesting to note that the standard torso strength itself can be viewed as leg strength discounted according to horizontal location (a comforting result which avoids ambiguity and discontinuities in predictions). With this latter simplistic model it was observed that 73% of the variability in job position strengths could be explained by interpolation of a standard test. It is believed that such fidelity is uncommonly good in comparison with other diagnostic test procedures. However, the remaining 27% of the variability being "unexplained" may preclude the use of the standardized tests as an adequate simulation of the actual job for a particular individual.

More research is now underway to develop and evaluate a better fit of standardized posture strength tests for individual employee selection and placement.

The prevention effectiveness of strength testing in general for employee selection and placement was evaluated by considering the employees to be grouped into three classifications. Some of the employees demonstrated quite a high strength capability in the four job position tests relative to the documented requirements of their prospective job. Thus, they were considered to be in an under-stressed group. Quantitatively, this meant that the average lifting strength required on the job was not more than half of the strength capabilities that the people demonstrated in the job position strength tests. A ratio of these two quantities was formed, i.e., the average strengths of the workers placed in a job was divided into the maximum strength requirement of the job, with the result entitled the Job Strength Rating. When people were found to be placed in jobs which more closely taxed their strength capabilities i.e., the job strength rating was between 0.5 and 1.0 they were classified as being considerably stressed. A third group of employees were found to be not capable of demonstrating as much isotonic strength as was determined to be required by their jobs. In other words, based on isotonic tests they were being overly stressed on their jobs, but were capable of performing the dynamic lifting required on the job by exerting great effort (apparently more than they were willing to demonstrate in the isotonic tests) combined with non-specific lifting devices (e.g., using a knee for support of object or body momentum) which were not included in the biomechanical evaluations of the job.

Medical incidents were classified by the plant physicians into three groups: (1) back pain, (2) musculoskeletal strain/sprain, dislocation, or fracture involving other than the back, and (3) contact injuries such as lacerations, bruises, or abrasions of a traumatic nature. Each incident was tabulated and for each job-employee strata incidence rates were calculated by dividing the number of incidents by the number of hours the employees were on the job. Also, severity rates were calculated by dividing the total number
of lost time and medical work restriction days for each incident by the number of hours the employees involved were on the job. These two rates were then corrected to a million man-hour exposure unit.

The back injury results for the three levels of relative strength loading are depicted in Fig 4. What this discloses is that as the job strength requirement approaches or exceeds the demonstrated isometric strengths of workers on the job, the mean incident and severity rates increase on a ratio of about 3:1.

Similar to the Job Strength Rating for determining the average stress level on a job, a measure of stress applicable to the individual employee was developed. The Employee Strength Rating was obtained by dividing the maximum strength requirement of the job by the individual's isometric strength. When this measure of stress was multiplied by the frequency of maximum exertions on the job, the results shown in Fig 5 were obtained for musculoskeletal stress related incidents other than the back.

In other words, other types of musculoskeletal strain injuries increase when a person is performing exertions close to or exceeding their demonstrated isometric strength on a fairly frequent basis. Neither the incidence nor severity rates of back pain showed such a frequency dependency, indicating an occasional over-stress of these tissues may be as just as or more damaging than more frequent stresses.

The contact type injuries to the skin were also found to be dependent upon the multiplicative effect of frequency of exertion and the high relative stresses of the exertions. Fig 6 depicts these results.

Conclusions and Discussion

It is concluded that the results of this latest longitudinal study further confirm the need to utilize some form of a strength testing program when placing people on jobs requiring significant manual materials handling. The incidence rate of back pain in this study is similar to that disclosed in the earlier study. The severity rates were not available in the earlier project, but the results of this most recent study clearly indicate that organic tissue damage in the back is either more severe or that people are prohibited from quickly returning to their jobs when the job is more physically demanding of their relative strengths. As it has been discussed often in the literature, the more time a person remains off the job for back pain, the greater the chance the episode has of becoming a permanent disability for the person.

The result indicating that back pain incidence and severity does not depend on either the frequency of maximum efforts on the job or the combination of frequency times the relative strength loading of the employees has a biomechanical implication. It may well be that the back tissues are subject to failure under occasional overstresses as when frequently stressed. In other words, when a person is performing an exertion close to his maximum strength, a sudden movement (i.e., slip) may cause tissue failure be it muscular, ligamentous or disc related. Thus, occasional physical exertions of a heavy nature can be as damaging as more frequent exertions, which, in fact, might strengthen the musculature over time and thus reduce the risk of future injury. Much more epidemiological work is needed in regard to the protective nature of strength training of the back and torso.

The musculoskeletal and contact injury results of this study further substantiate the potential gain that can be achieved by a systematic strength assessment and job placement program. This is particularly true when the exertions on the job occur with reasonable repetition.

The question of what particular test or battery of strength tests will provide adequate simulation of any specific collection of industrial jobs remains unresolved. For lifting tasks, standardization appears reasonable: perhaps with separate measures of gross arm and gross leg strength, a satisfactory interpolation would not
seriously affect test validity. For other tasks, such as when pushing and pulling loads, the question remains.

In summary, it is believed by these authors that the evidence for strength testing and placement is substantial. Specific placement and selection programs in industry should be undertaken using a strength performance criterion. Further delay cannot be justified when considering the large numbers of workers who are seriously harmed and often permanently disabled by overexertion in industry today.

The authors wish to acknowledge the cooperation of Western Electric Co., Inc. and Bethlehem Steel. Partial support for this work was provided by NIOSH Traineeship Grant No. 2T01-OH00161-04 and by NIOSH Contract No. CDC-99-74-62.

References