PHYSICAL WORKING CAPACITY AND FUNCTIONAL CAPACITY EVALUATION SYSTEM

(Version 2.0)

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SECTION I - OVERVIEW

Section I is an overview of the Physical Working Capacity (PWC) And Functional Capacity (FC) Evaluation System. Section I presents:

- A general description of the PWC/FC Evaluation System.
- Steps that need to be taken to use the system.
- General methods of matching the worker to the job.
- A general description of the contents of this manual.

1.0 PWC/FC EVALUATION SYSTEM

The PWC/FC Evaluation System evaluates an individual's capacity to perform physically demanding work tasks. Selecting capable workers not only increases productivity, but also reduces the risk of sustaining a musculoskeletal injury. System input includes the person's physical ability test results and demographic data. Output from the PWC/FC Evaluation system is a computer-generated report that assesses the person's PWC or FC in relation to tasks defined by three work families. The report is designed to make either of two employment decisions, which are:

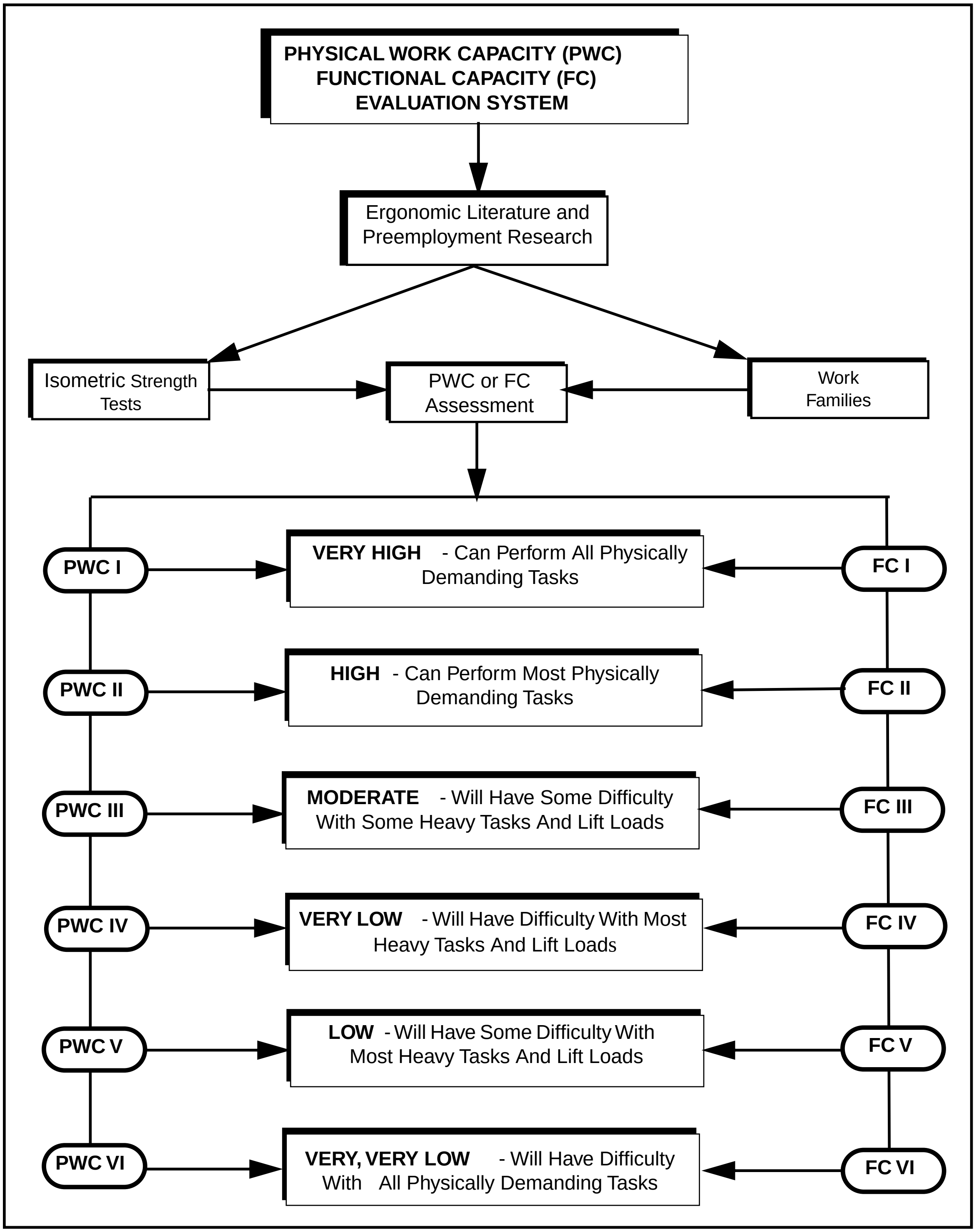
1. **Preemployment**. The PWC report evaluates a job applicant's capacity to perform physically demanding work tasks.
2. **Return to work.** The FC report not only evaluates an employee's capacity to perform physically demanding tasks at a level that allows for the safe return to work, but also evaluates the employee's general physical fitness.

A major source of data used to develop the PWC/FC Evaluation System comes from 20 years of preemployment research completed at the University of Houston.[1] The purpose of this research was to validate preemployment tests and define physiologically justified standards or "cut scores." The PWC/FC Evaluation System uses isometric strength tests to define the person's work capacity on a wide group of common, physically demanding industrial tasks. The ergonomic principle is to match the worker to the demands of the job. This validation research is the linkage between test results and job tasks. This connection is important for two major reasons.

1. The PWC/FC Evaluation System is congruent with federal legislation such as the Americans with Disabilities Act and the EEOC Uniform Guidelines. The computer-generated report is job-related. The individual is evaluated in relation to their capacity to perform the job.
2. The PWC/FC Evaluation System identifies those individuals who are physically capable of meeting the demands of the job. This not only enhances the productivity of the work force, but also reduces the risk of injury.

1. This research is listed in the references.

FIGURE 1. Graphic description of the PWC/FC Evaluation System.



The ergonomics literature and the University of Houston preemployment research provide the scientific foundation of the PWC/FC Evaluation System, which consists of four major, interrelated components. These are:

1. **General Work Families.** The work families provide a model for categorizing physically demanding industrial tasks. Table 1 describes these work families and the members that comprise each family.
2. **Physical Capacity Tests.** The physical capacity tests include isometric strength and fitness tests. The isometric tests provide a valid means for evaluating an individual's capacity to do the work tasks defined by the three general work families. The isometric tests are used for the PWC evaluation while the strength and fitness tests are used for the FC evaluation. The fitness tests evaluate the worker's aerobic fitness, body composition, and flexibility.
3. **Computer-Generated PWC/FC Report.** The physical capacity test and demographic data are used to generate a report that evaluates the person's PWC or FC. Equations developed from preemployment, exercise physiology, and ergonomic research are used to generate the person's PWC or FC report.

TABLE 1. Description of the PWC/FC Evaluation System work families.

WORK FAMILY	DESCRIPTION	FAMILY MEMBERS
Materials Lifting	Tasks that require lifting objects to various heights at various rates.	1. Level III: Not Acceptable Lift Weight 2. Level II: Maximum Acceptable Lift Weight. 3. Level I.: Maximum Repetitive/Difficult Lift Weight.
Maximum Force	Tasks requiring a brief, maximal force effort for a short period of time.	1. Push/Pull Tasks 2. Breaking Tasks
Endurance Work	Tasks requiring continuously enduring work for time periods lasting 15 minutes or longer.	1. Total Body Endurance Tasks 2. Upper Body Endurance Tasks

2.0 MATCHING THE WORKER TO THE JOB

While this manual does provide normative data, the key feature of the PWC/FC Evaluation System is that the computer-generated assessment of the individual estimates their capacity to perform industrial tasks. In order to match the person to the work, the physical demands of the work must be known. This involves conducting a task analysis. Provided next are examples of methods that can be used to define the work demands of a job.

- **Develop And Administer a Task Questionnaire.** Appendix C gives an example of a task questionnaire. Use this example and develop a questionnaire specific for the job. This would first involve talking to workers and supervisors to identify the tasks. These data can be used to identify the physically demanding work tasks.

- **Interview Workers.** A task questionnaire is best used for jobs with many physically demanding tasks. Many jobs are not that complex and the physically demanding tasks can often be identified by interviewing supervisors and job incumbents.
- **Complete A Biomechanical Analysis.** Once the physically demanding job tasks have been identified, go to the job site and observe the work and obtain data involving the demands of the task. These are the data that match the worker to task. To illustrate, measuring the force required to push or pull an object or break a nut can easily be obtained with the load cell unit. The weight and rate at which objects are lifted and transported can be easily noted. Once these data are known it is a simple matter of matching the person's computer-generated report with the demands of the job.

3.0 GETTING STARTED

The PWC/FC Evaluation System allows the user to select several options. Provided in this section are the options that you need to consider when using the computer program.

3.1 PWC or FC Evaluation

The PWC evaluation is a preemployment decision. The goal is to determine if an applicant has the physical capacity to do the work required by the job. In contrast, a FC evaluation determines if an injured employee is physically able to return to work. The PWC and FC computer-generated reports differ. The major difference is that the FC not only includes an evaluation of the employee's physical capacity to meet demands of work tasks, but also an assessment of the worker's general physical fitness.

3.2 Selection of Strength Tests

The five isometric strength tests of the PWC/FC Evaluation System are: grip, arm lift, shoulder lift, leg lift, and torso pull. The next section of this manual fully describes the test methods. Preemployment research completed at the University of Houston shows that the intercorrelations among the five tests are high and that different combinations of tests may be used without loss of accuracy. The system is designed to use: all five tests, two combinations of four tests, or just three tests. If only four tests are used, either the grip or leg test is dropped. Both the grip and leg tests are dropped when just three tests are used. The four combinations of strength tests that may be used are:

1. **All Five:** Grip, Arm Lift, Shoulder Lift, Torso Pull, Leg Lift
2. **Four I:** Arm Lift, Shoulder Lift, Torso Pull, Leg Lift
3. **Four II:** Grip, Arm Lift, Shoulder Lift, Torso Pull
4. **Three:** Arm Lift, Shoulder Lift, Torso Pull

There are several factors to consider when selecting a combination of isometric tests to use.

- **Muscle groups used to do the work.** The five tests measure the strength of the major muscle groups used to do physically demanding work. The muscle groups required to do the work should be linked with the tests.

- **Ease of testing.** It is our experience that the arm, shoulder, and torso tests are very easy to administer. The leg lift test can be difficult to administer because some find it difficult to assume the correct test position.
- **Test equipment.** In order to administer the grip strength, you should have either a JAMAR grip dynamometer or the electronic unit with two load cells. A single load cell electronic unit would require the movement from the grip test apparatus to the platform unit. This would be very time consuming.

3.3 Selection of Aerobic Fitness Test

The FC evaluation includes an assessment of the worker's aerobic capacity. The PWC/FC Evaluation System has two general methods to evaluate aerobic fitness (VO_{2max}), which are: 1) maximum treadmill test, and 2) the University of Houston non-exercise test. The maximum treadmill test uses either the Bruce or Balke treadmill protocol. If the maximum treadmill option is not selected, the default test is the U of H non-exercise test. The data used for the non-exercise test include: gender, age, height, weight, and self-report rating of physical activity. The aerobic fitness test methods are fully provided in a later section of this report.

3.4 Selection of Body Composition Method

The PWC/FC Evaluation System provides two body composition options. The first is percent body fat estimated from skinfold thickness. The second choice is body mass index (BMI), which is the ratio of height and weight. If skinfold fat is not measured, BMI is the default option of the FC evaluation.The body composition test methods are fully provided in a later section of this report.

3.5 Score Sheets

Once the test options are selected, score sheets need to be made. Appendix A provides examples of PWC and FC score sheets. While federal laws prohibit the use of age, gender, and anthropometric data such as height, weight, or skinfold fat when making pre-employment decisions, we recommend that these data be entered into the computer. The computer-generated PWC evaluation report will not include these demographic data, but they are important when developing reports for all those individuals who were tested. Also note that the procedure used to measure strength includes a warm-up trial and then two full-effort trials. Both full-effort trials (i.e., T1 & T2) must be entered into the computer. The average of the two trials is used to compute the person's strength score.

It is recommended that you use the score sheet examples to develop a PWC and FC score sheet that includes the test options selected and your organization information (e.g., test administrator, etc.). We recommend that all data be first recorded on the score sheet, then entered into the computer. It is always a good practice to keep the completed data sheets as a "hard copy" backup.

4.0 MANUAL OVERVIEW

In addition to Section I, the manual includes two additional, comprehensive sections. Section II provides a detailed description of the PWC/FC test methods. Included are complete test instructions for strength (PWC) and fitness testing (FC). The strength testing section gives the test instructions to measure grip, arm lift, shoulder lift, torso pull, and leg lift isometric strength. The fitness test section provides the methods for measuring the fitness components which are:

- Aerobic Fitness
- Body Composition
- Flexibility

Section III of the manual provides the scientific foundation of the PWC/FC Evaluation System. First, the three work families and members that comprise each family are described. Some believe that static tests cannot be used to measure one's capacity to perform dynamic work. The second part of Section III section presents the research that validates the use of static, or isometric, strength tests to evaluate a worker's capacity to do dynamic work tasks. The final part of section III is a comprehensive review of relevant ergonomic literature and preemployment research that supports the validity of the PWC/FC Evaluation System.

SECTION II - PWC/FC TEST METHODS

Section II includes the PWC/FC test methods and normative standards. The section is divided into two general parts, which are:

- **Isometric Strength Tests.** Test instructions are included to measure grip, arm, shoulder, torso, and leg strength.
- **Fitness Tests.** Test instructions are included to measure aerobic fitness, body composition, and flexibility.

5.0 STRENGTH TESTING METHODS

Presented in this section are the general isometric strength test methods. The "step-by-step" operation instructions of the Jackson Strength Evaluation System are provided with the equipment. Provided next is a discussion some basic equipment instructions. Following the equipment discussion is a presentation of test selection and test methods.

5.1 Basic Strength Test Equipment Instructions

Depending upon test load, the PWC tests can be administered using one load cell (Transducer A) or two load cells (Transducers A and B). If one load cell is used, the recommended procedure is to use one platform-chain-handle unit. After the arm and shoulder tests, the side braces will need to be attached to the platform in order to administer the torso pull test. This ensures stability when the platform is placed on end against the wall. With two load cells, the recommended procedure is to use two platforms, one for the arm and shoulder tests and the second for the torso pull test.

Listed next are the general procedures for testing strength with the JES.

1. The JES has the capacity to use two load cells. The load cell(s) are attached to the unit through ports (transducer A and B) located in the back of the unit.
2. Each load cell is calibrated for a specific port. Be certain the load cell is attached to the correct port. If you are using a single load cell, port "A" is the default.
3. The JES is a battery operated unit, but it is recommended that power supply be attached when testing.
4. Turn on the unit and wait for the MONITOR mode to appear, this will take about 10-15 seconds. A value of "0 lbs" should appear on the screen. If the value is not 0, push button #3 to zero the unit.
5. The default setting of the unit is a 3-second test trial. This consists of a 1-second prep time and 2-second test time. Force is not measured during the prep time, but is measured during the test time.[1]
6. To start the test trial, push button #1 and a "beep" sounds signaling to start the trial. Three seconds later a second beep sounds signalling the end of the test trial.

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1. The JES has the capacity to change the prep and test times. You are directed to the more detailed test manual for these program changes.

7. The unit records force in pounds and kilograms. The default setting is pounds. If for some reason, the setting is in kilograms, refer to the instruction manual to change to the default setting.
8. The unit records peak (P:+ xx lb) and average (A:+ xx lb) force for each test. Use the average reading.
9. The default setting for the JES is input channel A. In order to use the load cell attached to transducer B, the JES must be programed to use input channel B. The steps to change input channels are outlined next.
10. With the unit in the MONITOR mode, press button #2 located below the term “Param”.
11. Press button #2 again (below “Curs”) to activate the cursor. In the correct mode, you will see a blinking black rectangle on the “P”.
12. Press button #1 six times. This moves the cursor to flash on the displayed “C”.
13. Press button “#2” (located below “Sel”). This selects the screen needed to change the INPUT CHANNEL.
14. To change from INPUT CHANNEL A to B, PRESS BUTTON 2 located below “CH.B”. The screen changes to read: “C: INPUT CHANNEL = B”.
15. PRESS BUTTON 4 “OK” to accept the current INPUT CHANNEL selection.
16. Press button 4 “OK” again to return to the MONITOR MODE.
17. If “0 lbs” does not appear on the screen, push button 3 to zero the unit.
18. Initiate the test using CHANNEL B.
19. In order to change back to CHANNEL A from B, steps 1-4 must be repeated. At step 5, to change from INPUT CHANNEL B to A, PRESS BUTTON 1 located below “CH.A”. The screen changes to read: “C: INPUT CHANNEL = A”. Repeat steps 6 to 8 and you are back to CHANNEL A. The load cell attached to CHANNEL A is now the “live” test channel.

5.2 Strength Test Methods

All strength tests can be administered with the Jackson Evaluation System, but an optional method of measuring grip strength is with the JAMAR Hand Dynamometer. Presented in this section are the general methods and instructions for administering the strength tests. Instructions and methods for each test are provided in sections that follow. The grip test section includes instructions for testing grip strength with the Jackson Evaluation System and the JAMAR dynamometer.

The general procedures to follow for all tests are explained next:

1. For each test, the subject is given three trials, one warm-up trial at 50% effort and two trials at voluntary maximum.
   - First, administer a “warm-up” trial where the subject exerts force at 50% effort. Observe the trial and correct any problems.
   - Once the subject understands what to do, administer two trials for score. The trials should be at maximum, voluntary effort.
2. To insure a maximum voluntary effort, do the following:
   - Do not test the person in the presence of others.

- Do not give the subject any form of external motivation.
- Do not give the subject their score at the completion of the trial. If scores are to be given to the subject, they should be given after all testing is completed.

3. Prior to administering the first test, the following instructions should be given:

> "We are going to measure your maximum strength with isometric tests. This means you will be exerting force, but there will not be any movement. We will measure your maximum force with special test equipment. For each test, please follow these instructions."
>
> "The test will be demonstrated to you. If you do not understand what to do, ask questions."
>
> "For each test, we will give you three attempts. The first attempt will not count; we want you to try at only half (50%) effort. This attempt is a warm-up, and will help you figure out if you understand what to do. If you do not fully understand what to do, let me know."
>
> "Next, you will be given two attempts on each test. Try your best on both as your score will be the average of the two measurements."

4. The Jackson Strength Evaluation System provides the applicant with a stimuli (beep) to apply force and a second stimuli (flutter beep) to end the trial. Prior to administering the first test, give the applicant the following instructions.

> "When a test is to be given, I will ask you if you are ready. Shortly after the command 'ready,' you will hear a beep. This first beep is the signal to exert force. Three seconds later you will hear a second beep. Stop your force application on this second beep. You should apply a consistent, maximum effort during this period. Do not attempt to jerk."
>
> "Now, let me show you." Push button "1" and say, "Exert force on this beep, then relax after the final beep."
>
> "Are there any questions?"

The order in which the tests should be administered is:

1. Grip Strength (right followed by the left hand)
2. Arm Lift
3. Shoulder Lift
4. Torso Pull
5. Leg Lift

5.3 Grip Strength

The grip strength test measures the grip of both hands. Provided next are the equipment methods to test grip strength with the load cell (Jackson Grip Test) and the JAMAR hydraulic unit. The electronic unit with two load cells is needed if the Jackson Grip Test is used. It is very time consuming to move the load cell from the grip test apparatus to the platform unit.

5.3.1 Jackson Grip Test Methods

Figure 2 shows the grip test position with the Jackson Evaluation System. The steps to follow to test grip strength with the Jackson Evaluation System are given next.

FIGURE 2. Test position for the grip strength test using the Jackson Evaluation System.

1. Attach the load cell to the grip test unit by removing the two large black screw-knobs, placing the load cell in position, and replacing and tightening the screw-knobs.
2. Set the grip handle in the proper position. A centimeter scale is on the inside of the handle of the grip test unit. A black knob on the inside of the grip unit adjusts the grip spacing. The bottom of the handle should be set at 2.5 cm when testing adults.
3. Place the grip apparatus on a table and have the subject sit on a chair facing the table.
4. The subject's right grip is tested first followed by the left grip. The grip unit is held with the palm facing up.
5. The unit should rest comfortably in the hand with the fingers wrapped around the handle.
6. The arm being using to apply force should be slightly bent at the elbow and the hand not being used should be on top of the table, but not in contact with the test apparatus.
7. When in the correct position, the following instructions are to be given to the subject.

"The purpose of this test is to measure the strength of your grip. In this position, apply force by gripping the handle. You can move the grip unit on the table, but you cannot use your other hand. Now let's try your first attempt at half effort. Ready?"

Push the initiate button, and when the final beep has sounded, say:

"Do you have any questions?" Answer any questions and then say:

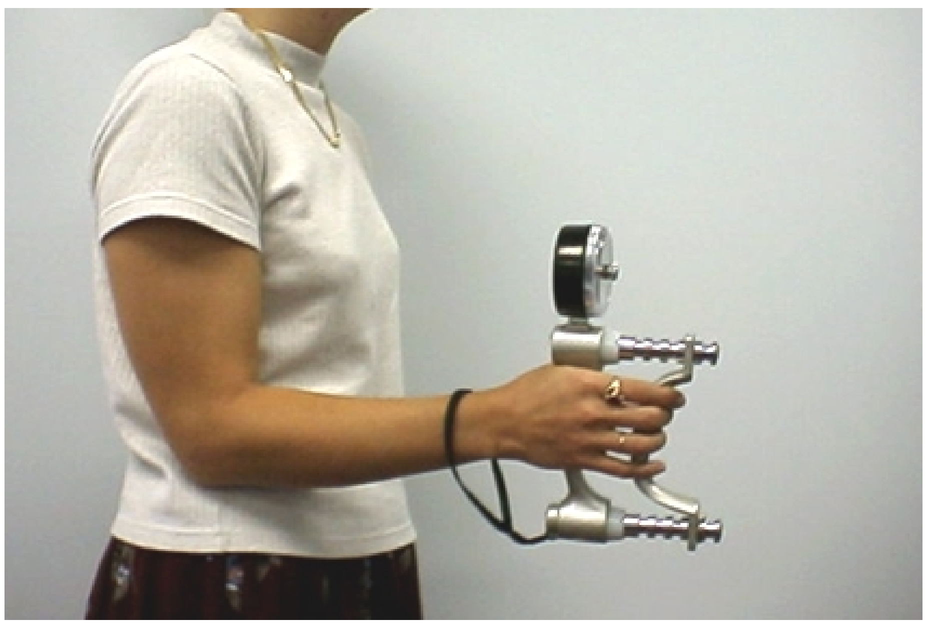
"Ready for your first maximum attempt?" Push button "1", and after the final beep, record the average score (A:+ xxlb). Reset the unit and administer the second trial.

8. Do not announce the score to the subject. The subject's grip strength is the average of the two maximum voluntary-effort trials.

5.3.2 JAMAR Grip Test Methods

The JAMAR hand dynamometer utilizes a hydraulic gauge with a peak-hold needle to record the highest strength effort. The following procedures need to be followed to measure grip strength (Figure 3) with the JAMAR unit.

FIGURE 3. Test position for the grip strength test using the JAMAR hand dynamometer.



1. The JAMAR displays grip force in pounds and kilograms. Grip strength is measured in POUNDS.
2. The maximum grip strength is recorded by a special peak-hold needle. After each test trial, reset the needle to "0".
3. The adjustable handle allows for five settings. Use settings "2" or "3", depending upon hand size.
4. Figure 3 shows the grip test position. The subject stands comfortably with the shoulder adducted and neutrally rotated. The elbow is flexed to 90° and the forearm and wrist are in neutral position. The subject's right and left grip are tested. Start with the right grip.

5. When in the correct position, the following instructions are to be given to the subject.

   "The purpose of this test is to measure the strength of your grip. In this position, apply force by gripping the handle with a single, forceful effort. We will first give you a trial at 50% effort. Next we will give you two maximum effort trials. Now let's try your first attempt at half effort. Ready?"

   After the trial make any corrections. Next, tell the applicant:

   "Now we will give you two maximum effort trials with your right hand. This will be followed with two maximum effort trials with your left hand. Ready."

6. Administer the two trials for a score for the right grip. Record the subject's score in POUNDS. This value is recorded by the peak-hold needle.
7. Reset the peak-hold needle to zero after each trial.
8. Once the right grip is tested, measure grip strength of the left hand.
9. Do not announce the score to the subject.
10. The subject's grip strength is the average of the four maximum-voluntary effort trials.

5.4 Arm, Shoulder, Torso, and Leg Strength

The arm, shoulder, torso, and leg strength tests are administered on the Jackson Strength Evaluation System. The handle-chain-platform unit is used to standardize these test positions.

5.4.1 Arm Lift

The arm lift test is administered with the Jackson Evaluation System with the load cell attached to platform. The following procedures are followed to get the subject into the test position.

1. First, demonstrate the test position to the subject and then have the subject assume the test position. Figure 4 shows the arm lift test position.
2. In proper position, the subject stands on the platform with arms at his/her side and elbows at a right angle (90° flexion). Find the cable/chain attachment that places the elbows at 90° in the test position. To set the height of lift bar:
   - Unsnap the bar from chain.
   - Raise or lower the chain to the desired height.
   - Snap the lift bar back onto the chain at the proper link.
   - The unused portion of the chain should hang beneath the bar.
3. Hold the handle with the palms up. Allow the subject to assume a hand placement width that is comfortable. This is about shoulder-width apart. The cable should be tight and at a right angle to the base. This is done by having the subject pull up and by moving forward or backward.
4. The purpose of this test is to measure the lifting strength of the arms. The subject is not allowed to lean back or use his/her legs (e.g., bending the knees and generating force with the legs). The force is exerted by lifting with the arms with the elbows at 90° flexion.

5. When in the correct position, the following instructions are to be given to each subject.

"The purpose of this test is to measure the strength of your arms. In this position, lift up with your arms. Do not lean back. Rather, lift up. Now let's try your first attempt at half effort. Ready?"

Push button "1", and when the final beep has sounded, say:

"Do you have any questions?" Answer any questions and then say:

"Ready for your first maximum attempt?" Push button "1", and after the final beep, record the average score (A:+ xxlb). Reset the unit and administer the second trial.

6. Administer the two trials for score and record the subject's average score.

7. Do not announce the score to the subject. The subject's score is the average of the two maximum voluntary-effort trials.

FIGURE 4. Test position for the isometric arm strength test. The angle of the arms is 90°.

5.4.2 Shoulder Lift Test

The following procedures are used measure shoulder lift strength.

1. The same bar setting used for the arm lift test is used for the shoulder lift.
2. To assume the correct position, the subject moves forward until the bar touches his or her body. The cable should be tight and at a right angle to the base.
3. With the palms facing the rear, the subject grabs the bar so that the inside of their hands is on the inside of the black handle. In this position the elbows are pointing out, away from the body. Figure 5 shows the shoulder lift test position.

FIGURE 5. Test position for the shoulder lift test.

4. This test measures the lifting strength of the shoulders. The subject is not allowed to lean back or use his/her legs (e.g., bending the knees and generating force with the legs). The force is correctly exerted by lifting up with the shoulders while the elbows point outward.
5. Once in the correct position, the subject is given the following instructions.

> "The purpose of this test is to measure the strength of your shoulders. Do not lean back, rather, lift up. Now let's try your first attempt at half effort. Ready?"

Push button “1”, and when the final beep has sounded, say: “Do you have any questions?” Answer any questions and say:

“Ready for your first maximum attempt?” Push button “1”, and after the final beep, record the average score (A:+ xxlb). Reset the unit and administer the second trial.

6. Administer the two trials for score and record the subject’s average score.
7. Do not announce the score to the subject. The subject’s score is the average of the two maximum voluntary-effort trials.

5.4.3 Torso Pull Test

The following procedures are used to get the subject into the test position to test torso pull[1] strength (Figure 6).

FIGURE 6. Test position for the torso pull test.

1. The lift bar is attached to a chain link that places the bar 17 inches from the base of the platform. The same chain setting is used for all subjects. The handle should be attached to the 8th link in the chain.
2. The platform is placed against the wall with the cable-chain unit at the bottom of the platform. The braces are connected to the side of the platform to provide stability.
3. The subject sits on the floor with their feet firmly against the platform and their legs straight.

1. The torso pull test was developed to replace the NIOSH torso lift test (NIOSH, 1977). Appendix B gives the research that shows the two tests are equivalent.

4. In this sitting position, the subject bends at the waist and grips the handle with the palms facing down. The hands should be about shoulder-width apart and the arms are straight. Figure 6 shows the torso pull test position.
5. In the test position, force is exerted by pulling and leaning back. The subject should not jerk, but should apply force in a consistent, forceful manner.
6. Place the subject in the correct test position, and give the following instructions.

   "The object of this test is to measure your capacity to pull back. Grip the bar with your palms facing down. From this position, lean back and pull. Apply a steady, forceful effort. Are there any questions?"

   Make sure the subject is in the proper position, and then say:

   "Now let's try your first attempt at half effort. Ready?" Push button "1", and when the final beep has sounded, say:

   "Do you have any questions?" Answer any questions and then say "Ready for your first maximum attempt?" Push button "1", and after the final beep, record the average score (A:+ xx lb). Reset the unit and administer the second trial.
7. Administer the two trials for score and record the subject's average score.
8. Do not announce the score to the subject. The subject's score is the average of the two maximum voluntary-effort trials.

5.4.4 Leg Lift Test

The following procedures are used to get the subject into the test position to test leg lift strength.

1. The same bar setting used for the torso pull test is used for the leg lift test, i.e., 17-inch height from the base.
2. The subject stands on the platform with their feet spread a comfortable distance. The bar is rotated 90° so the ends of the bar faces the front and back of the platform, i.e., the bar is between the person's legs.
3. The subject grips the bar with the palms facing each other. The hands are as close to the center of the bar as possible. In this position the bar is between the legs with the arms as close to the body as possible
4. The subject bends their knees, keeping the arms as close to the body as possible. Keeping the arms as close to the body as possible minimizes low back compression forces.
5. Once in position, tell the subject to look up. This makes the subject assume the correct position. Do not let the subject look down. Figure 7 shows the leg lift test positon.
6. In the test position, force is produced by exerting force with the legs. This duplicates lifting with the legs. The subject should not jerk; instead apply force in a consistent, forceful manner.
7. Place the subject in the correct test position, and give the following instructions.

   "The object of this test is to measure your leg strength. Grip the bar with your hands close together and palms facing each other. From this position, exert force with legs. Keep your arms next to your body. Your arms should be touching your body. Apply a steady, forceful effort. Are there any questions?"

Make sure the subject is in the proper position, and then say:

"Now let's try your first attempt at half effort. Ready?" Push button "1", and when the final beep has sounded, say:

"Do you have any questions?" Answer any questions and then say:

"Ready for your first maximum attempt?" Push button "1", and after the final beep, record the average score (A:+ xx lb). Reset the unit and administer the second trial.

8. Administer the two trials for score and record the subject's average score.
9. Do not announce the score to the subject. The subject's score is the average of the two maximum voluntary-effort trials.

FIGURE 7. Test position for the leg lift test.

5.5 Strength Testing Quality Control Checks

Not following the outlined test procedures can adversely affect test results. Provided next are methods you can take to insure proper test procedures are being followed.

5.5.1 Compare Peak and Average Score

The Jackson Evaluation System provides peak (P:+ xx lb) and average (A:+ xx lb) reading. It is our experience that the peak score should not be more than 15 pounds higher than the average reading. When the peak value is 15 pounds higher than the average score, the likely reason is that the subject stopped exerting force before the final beep. If this happens, remind the person to apply force until the final beep sounds and re-administer the trial.

5.5.2 Extreme Scores

Table 2 gives test score ranges that you can expect for men and women. About 95% of all scores should fall within this range. If a high proportion (> 10%) of the people tested fall outside the range, it is likely due to one of two reasons.

1. The tests are not being administered properly.
2. The group being tested is not typical of the general adult population, i.e., extremely weak or strong.

TABLE 2. About 95% of test scores should be within these ranges.

TEST	MALES	FEMALES
Grip Strength	58-158	28-98
Arm Lift	38-126	10-74
Shoulder Lift	47-178	13-94
Leg Lift	100-380	29-217
Torso Pull	130-336	38-203

5.6 Strength Standards

The PWC/FC Evaluation System uses the strength data to estimate the person's level of work capacity. The person's computer-generated PWC of FC evaluation is not based on norms. Rather, it defines the person's capacity to perform common work tasks. For example, it answers the question: Does the person have enough strength to lift 75 pounds from floor-to-knuckle height? The validation section of this manual gives the scientific evidence and rationale for this work-related assessment.

Tables 3 and 4 are normative strength data for the isometric strength tests. Provided are means and standard deviations for samples of male and female college students and industrial workers. The samples include those tested when participating in preemployment research completed at the University of Houston (college students and workers), and college students enrolled in the physical fitness course required of all students.

TABLE 3. Means, standard deviations, and sample sizes for isometric strength tests administered to male industrial workers and college students.

STRENGTH TEST	MALE INDUSTRIAL WORKERS			MALE COLLEGE STUDENTS		
	N	MEAN	SD	N	MEAN	SD
Grip	1178	111.5	23.2	311	95.9	25.6
Arm Lift	1424	89.6	19.0	971	72.4	22.2
Shoulder Lift	407	128.7	25.7	659	102.9	32.4
Leg Lift	246	247.9	63.4	122	213.1	73.8
Torso Pull	382	244.7	38.1	598	225.6	57.3

TABLE 4. Means, standard deviations, and sample sizes for isometric strength tests administered to female industrial workers and college students.

STRENGTH TEST	FEMALE INDUSTRIAL WORKERS			FEMALE COLLEGE STUDENTS		
	N	MEAN	SD	N	MEAN	SD
Grip	106	74.4	18.2	299	60.5	16.1
Arm Lift	204	52.6	13.6	1143	37.7	16.4
Shoulder Lift	115	70.1	19.2	844	51.7	19.3
Leg Lift	98	137.3	55.1	147	113.5	38.6
Torso Pull	48	161.1	41.4	805	119.0	40.1

6.0 FITNESS TEST METHODS

The Functional Capacity evaluation not only assesses work capacity, but also physical fitness. The fitness components include maximum aerobic capacity ($VO2_{max}$), body composition, and flexibility. These are common components included in adult fitness test batteries (Baumgartner & Jackson, 1999; Golding, Meyers, & Sinning, 1989). The fitness test results are not appropriate for preemployment testing unless the component has been shown to be related to the job.While it is often assumed that fitness is important for successful work performance, it is often difficult to link job performance with the fitness component. One such example is firefighting. Investigators found that a $VO2_{max}$ of 32 ml/kg/min was required to meet the demands of fighting fires (Sothmann et al., 1990).

In the absence of a link between fitness and job performance, the primary use of these fitness tests is rehabilitation, health promotion, and injury protection. The effect of low fitness on health is strong (Blair et al., 1989; Blair et al., 1995; Hubert et al., 1983; Leon, 1989; USDHHS, 1996). While not as strong, there is evidence showing that low fitness increases a worker’s risk of injury (Cady, Bishoff, O'Connell, Thomas, & Allan, 1979; Cady, Thomas, & Karwasky, 1985).

6.1 Maximum Aerobic Capacity

Maximum aerobic capacity or $VO2_{max}$, is the scientifically accepted measure of aerobic fitness which is, to a large extent, dependent on and limited by, the body’s ability to deliver oxygen to the working muscles. The lungs, heart, blood, circulatory system, and working muscles are all factors in determining one’s aerobic fitness. The most valid test of aerobic capacity is a maximum exercise test where $VO2_{max}$ is measured directly from expired gases. A treadmill is typically used to systematically increase power output (i.e., exercise intensity) until the person reaches their maximum capacity. While the gas analysis method[1] is the most valid measure of aerobic capacity, it is typically used just in research settings. The methods more often used are maximum treadmill performance, submaximal tests, and non-exercise methods.

The PWC/FC Evaluation System provides two methods of evaluating maximum aerobic capacity. These include: maximum treadmill time using either the Bruce or Balke protocol; and the U of H non-exercise test. While submaximal tests are common (Åstrand & Rodahl, 1986; Golding, Meyers, & Sinning, 1989), they were not included in the PWC/FC Evaluation System for two important reasons.

1. Submaximal tests are based on the physiological principle that heart rate increases at a linear rate with exercise. The test method uses submaximal heart rate to estimate maximum heart rate, which is used to estimate $VO2_{max}$ (Åstrand & Rodahl, 1986; Baumgartner & Jackson, 1999; Ross & Jackson, 1990). Any factor that affects heart rate response to exercise increases the inaccuracy of submaximal tests. Many medications prescribed for adults (e.g., beta blockers for hypertension) affect heart rate. This greatly limits the use of submaximal tests. Neither a maximum treadmill nor the U of H non-exercise tests are dependent upon heart rate.

1. This method is called indirect calorimetry.

2. Validation research showed that the U of H non-exercise test was more accurate than a submaximal test (Jackson et al., 1990a). The non-exercise tests have been shown to detect longitudinal changes in aerobic capacity (Jackson et al., 1995; Jackson et al., 1996b).

The PWC/FC Evaluation System provides two methods for evaluating maximum aerobic capacity. The treadmill test is a maximum exercise test while the U of H non-exercise test does not involve exercise. Factors to consider when selecting the test are:

- **Accuracy.** The maximum treadmill test is more accurate than the non-exercise test. You are directed to another source that compares the accuracy of these tests (Baumgartner & Jackson, 1999).
- **Risk.** A maximum treadmill test is performed to voluntary exhaustion. The potential for a cardiac problem during a maximal test is low, only about 1 event per 10,000 tests. Even with this low risk, caution needs to be exercised when testing adults, especially those at risk of cardiovascular disease. A maximal test needs to be administered under medical supervision (ACSM, 1991; ACSM, 1993).
- **Time and Expense.** The non-exercise test takes very little time and it requires no expensive equipment. In contrast, a maximal test needs medical monitoring. In addition to a treadmill, a maximal treadmill test requires blood pressure, 12-lead ECG, and emergency equipment. While the non-exercise test is less accurate than the treadmill test, it provides an excellent estimate of maximum aerobic capacity at no risk.

6.1.1 Maximum Treadmill Test

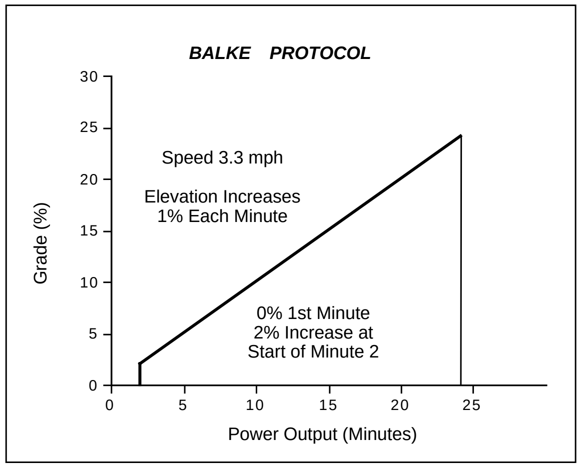
A maximum treadmill test involves having a person walk (or run) on a treadmill while the power output is systematically increased until the person's maximum aerobic capacity (VO_{2max}) is reached. Power output is increased by either increasing treadmill speed, increasing treadmill elevation, or both. The two most common maximum treadmill tests follow the Bruce and Balke protocols. About 71% of all tests given in the United States follow the Bruce protocol and about 10% use the Balke (Pollock, Wilmore, & Fox, 1984). Each is described next. While the speed and elevation can be manually set, most modern treadmills can be programmed to automate the power output of either protocol.

A maximal treadmill test is scored by the elapsed time in minutes to exhaustion. The PWC/FC Evaluation System requires that treadmill time (minutes and seconds) and protocol be entered into the computer. The computer-generated report uses maximal treadmill time and the protocol to estimate VO_{2max} from published equations (Baumgartner & Jackson, 1999; Foster, Jackson, & Pollock, 1984; Pollock et al., 1976).

It is important to remember that a maximal treadmill test needs to be administered under medical supervision. You are directed to other sources (ACSM, 1991; ACSM, 1993) for detailed discussions of treadmill test methods.

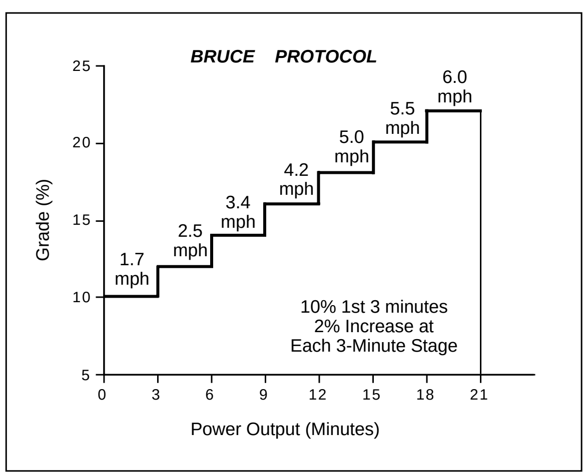
Balke Protocol . The Balke protocol uses a constant treadmill speed of 3.3 m.p.h. For the first minute of exercise, the elevation is set at 0% grade. At the start of minute two the elevation is increased to 2% grade and is then increased by 1% each minute of the test (see Figure 8). This protocol is not suitable for highly fit individuals, those with a VO_{2max} > 55 ml/kg/min. This is about 5% of the male adult population and less about 2% of the female adult population. The Bruce protocol is more suitable for these higher fit individuals.

FIGURE 8. The Balke protocol for measuring VO_{2max}. It tends to be better for lower fit subjects.



Bruce Protocol. The Bruce protocol consists of several three-minute stages that become progressively more demanding. The treadmill speed and elevation are increased at each new stage. Figure 9 shows the Bruce Treadmill Protocol. The Bruce protocol can be somewhat demanding for low fit (VO_{2max} < 30 ml/kg/min) individuals. The Balke protocol is more suitable for these lower fit individuals.

FIGURE 9. The Bruce protocol for measuring VO_{2max}. It tends to be suitable for high fit subjects.



6.1.2 Non-exercise Aerobic Fitness Test

Research conducted at NASA/Johnson Space Center showed that aerobic capacity can be estimated with excellent accuracy from the individual's age, gender, body composition, and self-report level of aerobic exercise. The original study (Jackson et al., 1990a) included over 2,000 men and women. A limitation of the study was that the sample size of the women was considerably smaller than the males. We recently published additional research with a much larger sample of women (Jackson et al., 1996b). The variables needed to use the non-exercise test and the relationship of each with aerobic capacity is described next.

1. **Age in Years.** Research (Buskirk & Hodgson, 1987; Jackson et al., 1995; Jackson et al., 1996b; Kasch, Boyer, VanCamp, Verity, & Wallace, 1990; Kasch, Wallace, & VanCamp, 1985) shows that aerobic capacity decreases with age.
2. **Gender.** Separate equations are used for men and women. The aerobic capacity of women is about 80% of men (Buskirk & Hodgson, 1987; Jackson et al., 1995; Jackson et al., 1996b; Kasch et al., 1990; Kasch et al., 1985).
3. **Self-report Level of Physical Activity.** Figure 10 gives the NASA scale used to rate level of physical activity. This rating has been found to be significantly correlated with measured VO_{2max} (Jackson et al., 1995; Jackson et al., 1990a; Jackson et al., 1996b). Changes in self-report exercise ratings have been shown to be related with aerobic capacity (Blair et al., 1995; Jackson et al., 1995; Jackson et al., 1996b).
4. **Body Mass Index (BMI).** The BMI is computed from the person's height and weight. BMI is inversely related to VO_{2max} (Jackson et al., 1990a).

Figure 10 shows the NASA self-report exercise scale. To use the scale, simply give the person the scale and ask them to select the number that best represents their level of physical activity for the past 30 days. Often, some will respond with two numbers. In these instances, the highest value is used. Table 5 gives estimated VO_{2max} values (Baumgartner & Jackson, 1999) for various combinations of the variables used with the non-exercise method.

6.1.3 Aerobic Capacity Standards

Aerobic capacity varies by age and gender. As a group, women have an aerobic capacity about 20% lower than men of a similar age. This is primarily due to hormonal differences that cause women to have a lower concentration of hemoglobin in their blood and a higher percentage of body fat. Aerobic capacity of adults decreases with age (Buskirk & Hodgson, 1987; Jackson et al., 1995; Jackson et al., 1996b). Tables 6 and 7 give aerobic capacity standards published by the American College of Sports Medicine (Gettman, 1993) for men and women adjusted for age group.

FIGURE 10. Scale for rating level of physical activity. The directions are to select one value that best represents level of physical activity for the previous month. The scale developed for use in the Cardiopulmonary Laboratory, NASA/Johnson Space Center, Houston, Texas.

NASA CODE FOR PHYSICAL ACTIVITY

Use the appropriate number (0 to 7) which best describes your general ACTIVITY LEVEL for the PREVIOUS MONTH.

DO NOT PARTICIPATE REGULARLY IN PROGRAMMED RECREATION SPORT OR HEAVY PHYSICAL ACTIVITY.

0 - Avoid walking or exertion, e.g., always use elevator, drive whenever possible instead of walking.

1 - Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration.

PARTICIPATED REGULARLY IN RECREATION OR WORK REQUIRING MODEST PHYSICAL ACTIVITY, SUCH AS GOLF, HORSEBACK RIDING, CALISTHENICS, GYMNASTICS, TABLE TENNIS, BOWLING, WEIGHT LIFTING, YARD WORK.

2 - 10 to 60 minutes per week.

3 - Over one hour per week.

PARTICIPATE REGULARLY IN HEAVY PHYSICAL EXERCISE SUCH AS RUNNING OR JOGGING, SWIMMING, CYCLING, ROWING, SKIPPING ROPE, RUNNING IN PLACE OR ENGAGING IN VIGOROUS AEROBIC ACTIVITY TYPE EXERCISE SUCH AS TENNIS, BASKETBALL OR HANDBALL.

4 -Run less than one mile per week or spend less than 30 minutes per week in comparable physical activity.

5 - Run 1 to 5 miles per week or spend 30 to 60 minutes per week in comparable physical activity.

6 -Run 5 to 10 miles per week or spend 1 to 3 hours per week in comparable physical activity.

7 -Run over 10 miles per week or spend over 3 hours per week in comparable physical activity.

TABLE 5. VO_2Max (ml/kg/min) estimates for selected age, body composition, and activity levels for women and men.

SELF-REPORT RATING	BMI-WOMEN				BMI-MEN			
	19	23	27	31	23	26	29	32
Age - 20 Years								
7	46.8	42.1	37.4	32.8	55.5	52.5	49.5	46.5
5	43.0	39.4	35.8	32.2	51.3	48.9	46.5	44.0
3	39.2	36.7	34.1	31.6	47.1	45.3	43.4	41.6
1	35.4	33.9	32.5	31.0	42.9	41.7	40.4	39.1
Age - 30 Years								
7	43.6	38.9	34.2	29.5	51.9	48.9	45.9	42.9
5	39.7	36.1	32.5	28.9	47.7	45.3	42.9	40.4
3	35.9	33.4	30.9	28.4	43.5	41.7	39.8	38.0
1	32.1	30.7	29.2	27.8	39.3	38.0	36.8	35.5
Age - 40 Years								
7	40.3	35.6	30.9	26.2	48.3	45.3	42.3	39.3
5	36.5	32.9	29.3	25.7	44.1	41.7	39.2	36.8
3	32.7	30.1	27.6	25.1	39.9	38.0	36.2	34.3
1	28.9	27.4	26.0	24.5	35.7	34.4	33.1	31.9
Age - 50 Years								
7	37.0	32.4	27.7	23.0	44.7	41.7	38.7	35.7
5	33.2	29.6	26.0	22.4	40.5	38.1	35.6	33.2
3	29.4	26.9	24.4	21.8	36.3	34.4	32.6	30.7
1	25.6	24.2	22.7	21.3	32.1	30.8	29.5	28.2
Age - 60 Years								
7	33.8	29.1	24.4	19.7	41.1	38.1	35.1	32.0
5	30.0	26.4	22.8	19.1	36.9	34.4	32.0	29.6
3	26.2	23.6	21.1	18.6	32.7	30.8	28.9	27.1
1	22.3	20.9	19.4	18.0	28.5	27.2	25.9	24.6

TABLE 6. ACSM aerobic capacity standards for men for contrasted by age group.

STANDARD	AGE GROUP (MEN)				
	20-29	30-39	40-49	50-59	≥ 60
Excellent	≥52	≥49	≥47	≥43	≥41
Good	49-51	46-48	44-46	40-42	38-40
Average	42-48	39-45	37-43	33-39	31-37
Fair	39-41	36-38	34-36	30-32	28-30
Poor	≤38	≤35	≤33	≤29	≤27

TABLE 7. ACSM aerobic fitness standards for women contrasted by age group.

STANDARD	AGE GROUP (WOMEN)				
	20-29	30-39	40-49	50-59	≥ 60
Excellent	≥43	≥40	≥38	≥34	≥34
Good	40-42	37-39	35-37	31-33	31-33
Average	33-39	31-36	29-34	25-30	25-30
Fair	30-32	28-30	26-28	22-24	22-24
Poor	≤29	≤27	≤25	≤21	≤21

6.1.4 Validity of Aerobic Capacity Tests

The validity of the maximum treadmill and non-exercise tests are well established. Concurrent validity has been established by correlating the test with VO_{2max} measured by indirect calorimetry. Regression models were used to provide an equation to estimate VO_{2max} (ml/kg/min) for the test. The PWC/FC Evaluation System uses these equations to estimate VO_{2max} (ml/kg/min). Table 8 give the results of this research. The interested reader is directed to other sources (Baumgartner & Jackson, 1999; Ross & Jackson, 1990) for a detailed discussion of the validity of these tests.

TABLE 8. Summary of aerobic capacity validation results of maximal treadmill and non-exercise tests.

REFERENCES	TEST	R	SEE
Foster, Jackson, & Pollock, 1984	Bruce Maximum Treadmill	0.97	3.5 ml/kg/min
Pollock et al., 1976	Balke Maximum Treadmill Time	0.88	3.5 ml/kg/min
Baumgartner & Jackson, 1999; Jackson et al., 1995	Non-Exercise, Men	0.74	5.4 ml/kg/min
Baumgartner & Jackson, 1999; Jackson et al., 1996	Non-Exercise, Women	0.82	4.7 ml/kg/min

6.2 Body Composition

Body composition is an important fitness component. High levels of body fatness are not only associated with medical problems, but also can affect one's level of physical performance. Being overweight increases one's risk for illnesses such as hypertension, diabetes, and heart disease and places one at a disadvantage when performing tasks that involve moving the body, such as climbing stairs.

Hydrostatic (or underwater) weighing is the accepted laboratory method used to measure body composition. This is a complex system requiring highly trained technicians and specialized equipment. Hydrostatic testing usually is conducted in a laboratory at a university, medical center, or specialized center such as the U.S. Olympic Training Center. The interested reader is directed to other sources (Baumgartner & Jackson, 1999; Lohman, 1992; McArdle, Katch, & Katch, 1991; Wilmore & Costill, 1994) for a detailed discussion of this method. Due to the expense and need for highly trained technicians and laboratory equipment, hydrostatically determined body composition is rarely used in field settings. The popular alternatives are body mass index and the skinfold method.

6.2.1 Body Mass Index

A common, simple method of assessing body composition is with a height and weight ratio. While several different height-weight ratios are available, the body mass index (BMI) is now the standard. The BMI is simply the ratio of weight in kilograms and height in meters squared. The PWC/FC Evaluation System computes BMI from the person's height and weight parameters. If the skinfold method is not selected, the default body composition measure of the FC evaluation is the BMI.

Public health standards (USDHHS, 1990) are used to evaluate the person's level of body composition from BMI. Table 9 gives these standards

TABLE 9. Public health standards to define male and female weight status from BMI.

GENDER	STANDARD	
	NORMAL WEIGHT	OVER WEIGHT
Females	<27.3	≥27.3
Males	<27.8	≥27.8

6.2.2 Skinfold Method

This involves measuring the double thickness of subcutaneous fat with a skinfold caliper. The skinfold caliper should conform to specifications established by the committee of Food and Nutrition Board of the National Research Council of the United States. The Lafayette caliper meets this standard.

Accuracy of the skinfold measurement is insured by using the correct caliper and having a trained technician measure skinfold fat at the proper locations. Improper site selection is probably the most common reason for error in measuring skinfold fat. All measurements are taken on the right side of the body. Research has led to the publication of equations that accurately estimate hydrostatically determined percent body fat from skinfold measurements (Jackson & Pollock, 1978; Jackson & Pollock, 1985; Jackson, Pollock, & Ward, 1980).

TABLE 10. Skinfold sites used to estimate percent body fat of men and women.

SKINFOLD	GENDER	TEST INSTRUCTIONS AND FIGURE
Chest	Male	The chest is the diagonal fold taken half the distance between the anterior auxiliary line and nipple for men (Figure 11).
Abdomen	Male	The abdominal site is the vertical fold taken at a lateral distance of approximately 2 cm from the umbilicus (Figure 11).
Triceps	Female	The triceps is the vertical fold on the posterior midline of the upper arm (over the triceps muscle), halfway between the acromion and olecranon processes. The elbow should be extended and relaxed (Figure 12).
Suprailium	Female	The suprailium is the diagonal fold above the crest of the ilium at the spot where an imaginary line would come down from the anterior axillary line (Figure 12).
Thigh	Female & Male	The thigh is the vertical fold on the anterior aspect of the thigh midway between hip and knee joints (Figures 11 and 12).

Separate skinfold equations are needed for men and women. Each involves measuring three skinfold sites. Table 10 gives the sites for men and women. Provided in the table are descriptions of the sites used for men and women and reference in the figure showing correct caliper location. The bold "cross symbol" on the figure shows the proper location. The long line gives the "line" of the fold and the small cross line shows the point where the measurement is taken.

FIGURE 11. Caliper location for measuring chest, abdominal, and thigh skinfolds of men.

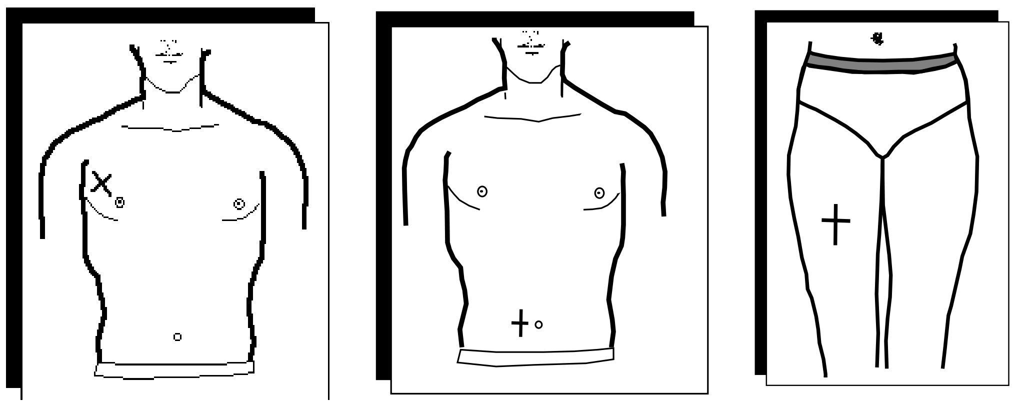
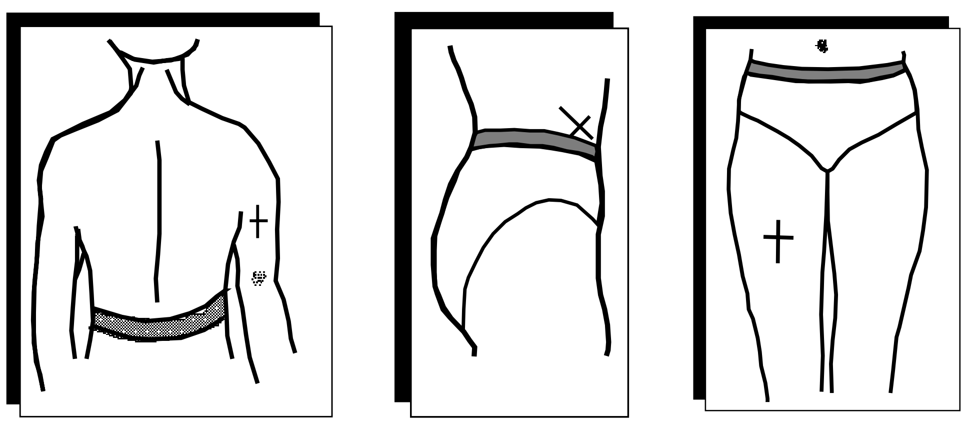


FIGURE 12. Caliper location for measuring triceps, suprailium and thigh skinfolds used for women.



6.2.3 Skinfold Test Methods

When taking a skinfold measurement, the left hand pinches and pulls the skin and the caliper is held in the right hand. Grasp the skinfold firmly by the thumb and index finger. The caliper is perpendicular to the fold at approximately 1 cm (0.25 in) from the thumb and forefinger. Then release the caliper grip so that full tension is exerted on the skinfold. Use the pads at the tip of thumb and finger to grasp the skinfold. Testers may need to trim their nails. Read the dial to the nearest 1 mm approximately one to two seconds after the grip has been released. A minimum of two measurements should be taken. If they vary by more then 2 mm, a third should be taken.

If consecutive fat measurements become smaller and smaller, the fat is being compressed; this occurs mainly with "fleshy" people. The tester should go on to the next site and return to the trouble spot after finishing the other measurements. The final value will be the average of the two that seem to best represent the skinfold fat site. Typically, the tester should complete a measurement at one site before moving to another. It is better to make measurements when the skin is dry, because when the skin is moist or wet the tester may grasp extra skin (fat) and get larger values. Measurements should not be taken immediately after exercise or when a subject is overheated, because the shift of body fluid to the skin will increase skinfold size. Practice is necessary to grasp the same size of skinfold consistently at the same location every time. Consistency can be ensured by having several technicians take the same measurements and comparing results. Proficiency in measuring skinfolds may take practice sessions with up to 50 subjects.

6.2.4 Percent Body Fat Standards

Different percent body fat standards are needed for men and women. Women not only have a higher percentage of their weight in storage fat (measured with the caliper), but also in essential fat consisting of lipids of the bone marrow, central nervous system, mammary glands, and other organs. Because of this additional storage fat, the percent body fat of women tends to be about 7 to 8% higher than men (Jackson & Pollock, 1978; Jackson et al., 1980). Tables 11 and 12 give the percent body fat standards recommended by the American College of Sports Medicine (Gettman, 1993).

TABLE 11. Percent body fat standard for women contrasted by age group.

STANDARD	AGE GROUP (WOMEN)			
	≤ 30	30-39	40-49	≥50
High	>32%	>33%	>34%	>35%
Moderately high	26-32	27-33	28-34	29-35
Optimal range	15-25	16-26	17-27	18-28
Low	12-14	13-15	14-16	15-17
Very low	≤11%	≤12%	≤13%	≤14%

TABLE 12. Percent body fat standard for men contrasted by age group.

STANDARD	AGE GROUP			
	≤ 30	30-39	40-49	≥50
High	>28%	>29%	>30%	>31%
Moderately high	22-28	23-29	24-30	25-31
Optimal range	11-21	12-22	13-23	14-24
Low	6-10	7-11	8-12	9-13

STANDARD	AGE GROUP			
Very low	≤5%	≤6%	≤7%	≤8%

What is a desirable percent fat standard for adults? Being seriously overweight clearly increases one's risk of heart disease, hypertension, and diabetes, and results in a lower life expectancy. Still, too many Americans, especially young women, are overly concerned about being too thin. Being underweight also can result in serious health problems. Athletes generally have a lower percent body fat than the total population. The percent body fat level depends on the athlete's gender and the event performed. Highly trained endurance athletes (e.g., distance runners) will normally have very low levels of body fat. The average percent body fat of world class distance runners is very low, averaging about 5% for men and ranging from 12% to 15% for women. This is an unrealistically low level for most who are not exercising to the level of these athletes. Most world class runners run from 10 to 15 miles each day of the week. At this mileage, they expend over 1,000 kilocalories a day just from exercise.Table 13 provides a description of each standard (Baumgartner & Jackson, 1999). Unlike the other fitness components, percent fat categories below what is considered to be average does not necessarily mean a higher level of fitness. For general health concerns, the desired level of body composition is the "Optimal Range" category.

TABLE 13. Description of percent body fat standard.

STANDARD	DESCRIPTION OF THE STANDARD
High	Percent fat at this level indicates the person is seriously overweight to a degree that this can have adverse health consequences. The person should be encouraged to lose weight through diet and exercise. Maintaining weight at this level for a long period of time places the person at risk of hypertension, heart disease, and diabetes. A long-term weight loss and exercise program should be initiated.
Moderately High	It is likely that the person is significantly overweight. It would be wise to carefully monitor people in this category and encourage them not to gain additional weight.
Optimal Range	It would be highly desirable to maintain body composition at this level.
Low	This is an acceptable body composition level, but there is no reason to seek a lower percent body fat level. Loss of additional body weight could have health consequences.
Very Low	A percent fat level in this range is often reached by high-level endurance athletes who are in training. Being this thin may carry its own additional mortality. Individuals this low, especially females, may be at risk of having an eating disorder such as anorexia nervosa.

6.2.5 Validity of Body Composition

Hydrostatically determined percent body fat is the "gold standard" of body composition. The Jackson-Pollock equations (Jackson & Pollock, 1978; Jackson et al., 1980) have become the standard for evaluating adults with skinfold fat. Body mass index (BMI) is now the accepted height-weight ratio used to evaluate body composition. While the BMI is more feasible for mass testing, it is less valid than the generalized skinfold equations. Table 14 summarizes the concurrent validity results. The interested reader is directed to other sources (Baumgartner & Jackson, 1999; Lohman, 1992) for a more detailed discussion of the validity of these body composition field methods.

TABLE 14. Summary of body composition validation results BMI and Skinfold fat.

STUDY	TEST	R	SEE
Baumgartner & Jackson, 1999	BMI, Men	0.69	5.8 % fat
Baumgartner & Jackson, 1999	BMI, Women	0.70	5.1 % fat
Jackson & Pollock, 1978	Skinfolds, Men	0.90	3.4 % fat
Jackson et al., 1980	Skinfolds, Women	0.85	3.8 % fat

6.3 Flexibility - Sit and Reach Test

Flexibility is the range of movement about a joint. Individual differences in flexibility depend on physiological characteristics that influence the extensibility of the muscles and ligaments surrounding a joint. It is generally believed that a degree of flexibility in the back and hamstring muscle groups is essential for the prevention of lower back disorders. It is for this reason that the sit-and-reach test is a common test used to measure physical fitness of adults (Golding et al., 1989). Provided next are the procedures for measuring flexibility.

The objective of the sit and reach test is to evaluate the flexibility of the lower back and posterior thighs. Figure 13 shows the correct test procedure. Below are steps to follow when administering this test.

1. With the shoes removed, the applicant sits with their feet flat against the test apparatus. Their knees are fully extended.
2. To perform the test, the subject extends their arms forward with their hands placed on top of each other. The subject reaches forward, palms down, along the measuring scale. The tips of the fingers are against the maximum indicator.
3. Stretch as far as possible and hold the position for one second.
4. The score is the farthest point reached measured to the nearest 0.25 inch. The distance is obtained from the maximum indicator. Tables 15 and 16 give normative standards.
5. The procedure is repeated for a total of two trials.

FIGURE 13. Test position for testing flexibility.

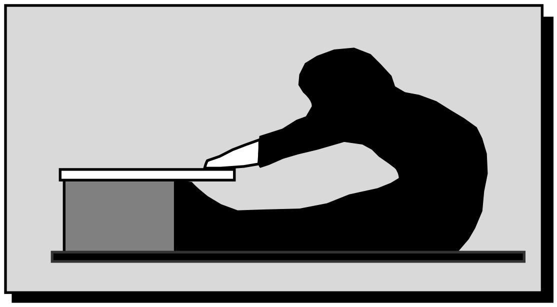


TABLE 15. Flexibility standards for men.

STANDARD	AGE GROUP (MEN)				
	20-29	30-39	40-49	50-59	≥60
Excellent	>21	>20	>19	>18	>17
Good	19-21	18-20	17-19	16-18	15-17
Average	13-18	12-17	11-16	10-15	9-14
Fair	10-12	9-11	8-10	7-9	6-8
Poor	<10	<9	<8	<7	<6

TABLE 16. Flexibility standards for Women.

STANDARD	AGE GROUP (WOMEN)				
	20-29	30-39	40-49	50-59	≥60
Excellent	>23	>22	>21	>20	>19
Good	22-23	21-22	20-21	19-20	18-19
Average	16-21	15-20	14-19	13-18	12-17
Fair	13-15	12-14	11-13	10-12	9-11
Poor	<13	<12	<11	<10	<9

SECTION III - SCIENTIFIC BASIS OF THE PWC/FC SYSTEM

Section III summarizes the ergonomic literature and preemployment research that provides the scientific foundation of the PWC/FC Evaluation System. First the ergonomic literature is reviewed. This literature provides the basis for the System's work families. Next, the general research supporting the use of isometric tests for estimating dynamic work performance is presented. The final part of Section III is a review of the preemployment research supporting the validity of the PWC/FC Evaluation system. A comprehensive bibliography is provided at the end of the section.

7.0 WORK FAMILIES

Ergonomic (Ayoub, 1982; Snook, 1978; Snook & Ciriello, 1991; Waters, Putz-Anderson, Garg, & Fine, 1993) and preemployment research (Hogan, 1991; Jackson, 1994) document that physically demanding jobs are largely dependent upon muscular strength.The University of Houston preemployment research not only validated the strength tests of the PWC/FC Evaluation System, but also led to the development of a comprehensive model that categorizes physically demanding tasks within three work families. The PWC/FC Evaluation System further divides the work families into more specific family members resulting in a comprehensive group of physically demanding work tasks. The work families are discussed next.

7.1 Work Family I: Materials Lifting

Many industrial jobs require workers to lift objects (e.g., boxes and bags) in many different ways. Loads are lifted to different heights at different rates. Additionally, workers use a variety of postures when lifting. The physical capacity of the lifter is not only important for being able to lift a load, it is also a major risk factor in injury. Medical research shows that about 50% of industrial low back injuries are caused by materials lifting tasks that are too heavy for the lifter (Snook, Campanelli, & Hart, 1978). The ergonomic approach to reducing back injuries caused by lifting is to match the worker and the job. This is done in two ways.

1. **Job Redesign.** Change the job demands to fit the industrial population (Ayoub, Mital, Bakken, Asfour, & Bethea, 1980). This involves engineering the risk out of the task.
2. **Worker Selection.** When job redesign is not an option, select workers who have the physical capacity to meet the demands of the job (Ayoub, 1982).

7.1.1 Job Redesign

The principle ergonomic technique of redesigning materials handling tasks is to define acceptable lift weight loads for the industrial population (NIOSH, 1981; Snook, 1978; Snook & Ciriello, 1991; Waters et al., 1993). Engineers report that several factors affect lift difficulty. These factors are the basis of NIOSH lift equation (Waters et al., 1993).

Table 17 describes the factors of the NIOSH equation and illustrates how they influence lift difficulty.

The NIOSH equation (Waters et al., 1993) defines “safe” lift standards for industrial populations. Physiological, biomechanical, and psychophysical criteria were used to develop the lift equations. The physiological criteria related to repetitive lifting. The biomechanical criteria are based on low back (L5/S1) compression forces. The psychophysical approach is based on worker perception of lift difficulty. This psychophysical research has led to the publication of maximum acceptable lifting levels and work rates for industrial populations (Ciriello & Snook, 1983; NIOSH, 1981; Snook, 1978; Snook & Ciriello, 1974; Snook & Ciriello, 1991; Snook & Irvine, 1969; Snook, Irvine & Bass, 1970). Marris and associates (Marris, 1999) examined the role of each NIOSH factor (Table 17) on low-back disorders. They reported that the weight load, horizontal and distance factors were the parameters associated with risk of back injury.

TABLE 17. The NIOSH ergonomic factors* that affect the difficulty of materials handling tasks.

NIOSH FACTOR	DESCRIPTION	COMMENTS
Weight Load	Weight of load lifted.	Heavier weight loads increase lift difficulty.
Horizontal	Distance from object lifted and the lifter’s feet.	Longer load-moment arm (further away from the body) increases lift difficulty.
Vertical	Distance from knuckle height to the starting location of the load.	Lift difficulty increases as start of the lift moves away from knuckle height, i.e, lift from the floor.
Distance	Distance the load travels from the start of the lift to the finish.	Longer distance the load is moved, the greater the lift difficulty.
Frequency	The number of times a lift is repeated within a work duration.	Increasing the number of times the load is lifted per minute increases lift difficulty.
Asymmetry	Lifting and turning.	Twisting increases lift difficulty and risk of injury.
Coupling	Type of handhold.	Poor handhold increases lift difficulty.

*From (Waters et al., 1993)

7.1.2 Worker Selection

The primary purpose of the NIOSH lift equation (Waters et al., 1993) is to identify physically demanding materials lift tasks and redesign the task to fit the industrial population. A major limitation of the NIOSH model is that the industrial population is defined by the load that the 75th percentile women can handle. Said differently, the lift standard is a weight load that 75% of female industrial workers can comfortably lift. This is an unrealistically low lift weight. For example, the NIOSH recommended floor-to-knuckle height lift weight load (RWL) is 10 kilograms (22 pounds), far below the physical capacity of many stronger individuals.

The NIOSH lift equation used psychophysical lift research as one of its principal criterion for defining RWL. A major limitation of the NIOSH model is that it does not recognize the well documented strength differences that exist among individuals, and that strength affects psychophysical lift capacity (Hidalgo et al., 1997; Jackson et al., 1997). The psychophysically defined lift values for female workers are lower than the values for males (Snook & Ciriello, 1991). This gender difference is due to the well documented gender differences in strength. Women have about 50% of the strength of men

(Baumgartner & Jackson, 1999; McArdle et al., 1991; NIOSH, 1977; Wilmore & Costill, 1994).While job redesign is an effective ergonomic strategy, it is not always possible. When the demands out a materials lift task cannot be engineered out of the task, the second approach is to select workers who are physically able to meet the demands of the task (Ayoub, 1982). Research has shown that materials lift capacity is a function of fat-free weight (Vogel & Friedl, 1992), or, more correctly, strength (Jackson et al., 1997). Fat-free weight is the body's force producing component and is highly correlated with isometric strength (Jackson et al., 1997). The feature of the PWC/FC Evaluation System is that it defines the person's lift capacity by their physiological capacity.

7.1.3 PWC/FC Lift Levels

The materials lifting family consists of three levels. The computer-generated report defines the weight load for the person that is beyond the lifter's capacity (Level I) and acceptable for lifts differing in ergonomic difficulty (Levels II and I). The PWC/FC evaluation system defines the lifter's physiological capacity from their isometric strength. The factors of the NIOSH lift equation (Waters et al., 1993) and risk factors identified by Marris and associates (1999) define ergonomic difficulty. The three levels are defined next.

LEVEL III: Not Acceptable Lift Weight.

Level III lift weights are those that are too heavy for the individual. If the person is able to lift loads equal or heavier than the LEVEL III lift weight, the lift will be a struggle and increase their risk of injury.

LEVEL II: Maximum Acceptable Lift Weight.

The person's LEVEL II lift load is the maximum weight that the person should lift. Table 18 provides the ergonomic characteristics of LEVEL II lifts.

LEVEL I: Maximum Repetitive/Difficult Lift Weight.

LEVEL I lifts are more difficult than LEVEL II lifts, and for this reason the lift weight is lower. See Table 18 for the ergonomic characteristics of LEVEL I lifts.

TABLE 18. NIOSH factors that define level II and level I lift tasks.

NIOSH FACTOR*	LEVEL II LIFT CHARACTERISTICS	LEVEL I LIFT CHARACTERISTICS
Lift Height	Just to knuckle height.	As high as shoulder height.
Work Rate	Infrequent work rate, no more than 1 lift every 4 hours.	Both infrequent and frequent, repetitive lifts.
Horizontal Distance	Size of the load and work environment allow the load to be kept close to the body.	Lift loads that can or cannot be kept close to the body, e.g., oversized box or a work environment that forces the worker to reach out for the object being lifted.

*From Waters et al., 1993.

7.2 Work Family II: Maximum Force

There are several industrial tasks that require the worker to exert a brief, forceful contraction. The maximum force tasks of the PWC/FC Evaluation System are divided into two family members: 1) Push/pull tasks and 2) Breaking tasks.

7.2.1 Push/Pull Tasks

Many tasks require workers to exert maximum force by pushing or pulling a heavy object. Examples are “tipping” a heavy 55-gallon drum, pulling a heavy hospital bed, and moving a container or dolly full of freight (Jackson, Osburn, Laughery, & Young, 1993). In the push or pull position, the worker’s hands are placed on the object being moved between waist and shoulder height. The force is not only generated by the involved muscle groups, but also the worker’s body weight. Some force can be generated by “leaning into,” or “pulling away” from, the object being pushed or pulled.

7.2.2 Breaking Tasks

Breaking tasks require a worker to apply force to a tool (e.g., valve wrench, pipe wrench, etc.) to “break” a nut or “crack” an industrial valve. The capacity to apply force varies by body position. In some work environments only the upper body can be used to generate torque. For other tasks, the work environment allows the worker to apply force to a wrench with both their upper and lower body. The PWC/FC Evaluation System’s computer-generated report estimates the individual’s upper body and total body torque generation capacity (Jackson, 1998). In the workplace the length of the load-moment arm of the tool affects the person’s torque production capacity. This is controlled by estimating the person’s capacity in foot-pounds. The characteristics of the upper and total body tasks are:

- **Upper Body Breaking Capacity.** These tasks involve applying force while in a standing or kneeling position. The primary function of the lower body is to provide a base of support; the legs are not in a position to apply force effectively. An example would be cracking an industrial value at about chest height by applying force to a valve wrench by pushing or pulling.
- **Total Body Breaking Capacity.** Some work environments allow the worker to assume a posture that permits him/her to generate force, not only with the upper body, but also their legs. An example would be applying force in an upward direction when the worker can assume a position that allows him/her to bend their knees and generate upward force using both their legs and upper body.

7.3 Work Family III. Endurance Tasks

Endurance work tasks are those that involve repetitive, continuous work for time periods lasting 15 minutes or longer. The scientific units of measurement that express endurance work capacity are oxygen uptake in liters per minute (L/min) and energy expenditure expressed in kilocalories per minute (kcal/min). Caloric expenditure is computed from oxygen uptake. About 4.8 kilocalories are expended for each liter of oxygen a person consumes (McArdle et al., 1991). The energy expenditure required to perform recreational and occupational physical tasks is published in exercise physiology texts (Brooks & Fahey, 1984; Durnin & Passmore, 1967; McArdle et al., 1991).

The maximum intensity that one can work at is about 70% of their maximum aerobic capacity, i.e., VO_{2max}. The PWC/FC Evaluation System gives the individual's estimated capacity to work at this rate. In addition to the general energy expenditure estimates, the computer-generated report gives the individual's work productivity on benchmark endurance tasks. The validation section of this manual gives the linkage between strength, endurance, and job performance. The family of endurance work tasks has two family members, total body and upper body endurance tasks.

7.3.1 Total Body Endurance Tasks

Many industrial tasks involve repeated lifting and transporting materials for an extended duration of time. In addition to the total body energy expenditure assessments, the program estimates the individual's work capacity to do two benchmark, total body endurance tasks.

- **50-pound Bag Transport.** This benchmark endurance task (Jackson & Osburn, 1983) involves repeatedly lifting 50-pound bags from a pallet, transporting them nine feet and placing them on a table, i.e., knuckle height. The computer-generated report of the PWC/FC Evaluation System gives the person's work capacity in pounds moved per minute.
- **Rapid Materials Transport.** This benchmark endurance task (Jackson et al., 1993) involves rapid lifting and transporting boxes that are varied in weight a short distance (≈ 6 feet). The boxes weights range from 2.5 to 75 pounds (Mean = 15.9 ± 19.1 pounds). The computer report of the PWC/FC Evaluation System gives the person's capacity to transport material in pounds moved per minute.

7.3.2 Upper Body Endurance Tasks

These tasks require repetitive muscular action that comes primarily for the arms. An individual's energy expenditure capacity for upper body endurance tasks is lower than their total body because less muscle mass is available for work. The function of the legs is to provide a solid base of support. Provided next are two benchmark upper body endurance work tasks.

- **Valve Turning.** A common industrial task is opening and closing industrial valves. This involves continuous arm work that takes as long as 15 minutes to complete. Task difficulty is not only dependent on the duration of work, but also the intensity, i.e., power output. Task analyses from major chemical and refining facilities (Jackson, 1998; Jackson, Osburn, Laughery, & Vaubel, 1990b; Jackson, Osburn, Laughery, & Vaubel, 1992) showed that the typical power output required to open or close an industrial valve is about 1,400 foot-pounds of torque per minute. The computer-generated report estimates the person's capacity to work for 15 minutes at this power output.
- **Shoveling.** This benchmark upper body endurance task involves repeatedly shoveling material over a 3.5-foot wall (Jackson, Osburn, & Laughery, 1991). The PWC/FC Evaluation System computer program assesses the person's shoveling capacity in pounds per minute.

8.0 ISOMETRIC VS. DYNAMIC STRENGTH

Muscular strength is the maximum amount of force that a muscle group can exert. Muscle contractions can be either dynamic or static. Static contractions do not involve movement and are termed isometric strength. Dynamic contractions involve movement, either concentric, in which the muscle shortens, or eccentric, in which the muscle lengthens. The dynamic forms include isotonic and isokinetic strength. Isotonic involves moving a weight against gravity. Lifting the weight uses a concentric contraction, while lowering the weight uses an eccentric contraction. Isokinetic involves muscle contractions at a fixed speed.

8.1 Overview of Strength Testing

Isometric strength is the maximum force that a muscle group can exert without movement. Tests of isometric strength are easy to perform as they require only a single, maximal contraction. Isotonic strength is measured by determining the maximal force that a muscle group can exert with a single contraction. An isotonic strength test measures the maximum weight that can be lifted with a single repetition. This is the one-repetition maximum test (1-RM). Free weights or progressive resistance equipment is used to measure 1-RM strength. The most difficult part of the test is to find the subject's maximal load. Isokinetic methods measure torque through a defined range-of-motion while keeping the speed of movement constant. The equipment used to measure isokinetic strength uses a load cell interfaced with a computer. The computer unit controls the speed of movement and measures torque. This yields the muscle group’s torque curve for the selected constant velocity. Both muscle strength and the velocity of movement affect the shape and magnitude of the curve. As the muscle contracts at a faster rate, it cannot generate as much torque so a lower curve is obtained. Test results from different test centers are not comparable unless the sites use the same equipment and the same test velocity.

While isokinetic testing used to be very popular, it has lost its appeal. There are three basic reasons for this (Baumgartner & Jackson, 1999). First, isokinetic equipment is very expensive. Second, managed health care corporations have dramatically reduced the amount of money they will pay for strength evaluations. Last, isokinetic tests are largely open kinetic chain and the current rehabilitation philosophy is to use closed kinetic chain. While isokinetic tests produce extensive computer-generated reports, there is no evidence that isokinetic strength tests are valid for preemployment testing.

8.2 Dynamic Work Sample Tests

Dynamic work sample tests are often used in employment rehabilitation settings. Assume that a job requirement is to lift a box (e.g., 75 pounds) from floor-to-knuckle height. An example of a dynamic work sample test would be a pass/fail test of lifting a 75-box from the floor and placing it on a table. While this work sample test has excellent face validity, dynamic work sample tests have four important limitations.

- **Maximum Capacity.** The successful completion of the lift indicates that the person can lift 75 pounds, but it does not provide any information about the lifter’s maximum capacity (Ayoub, 1982). Assume that individuals who differ in strength both pass the 75-pound work sample lift test. It may be very difficult for the weak person, but easy for the stronger person. The stronger person would have more potential to be a productive worker.

- **Risk Of Injury.** Individuals tend to be highly motivated to pass a preemployment test. A highly motivated applicant is more likely to sustain a test-related musculoskeletal injury if the work sample test requires the person to lift near or exceed their physical capacity (Ayoub, 1982). To illustrate, we observed that the work sample test to be hired gas company construction workers was to lift and transport a 90-pound jackhammer (Jeanneret & Associates, 1990). Such a work sample test would exceed the physical capacity of many, and increase the risk of injury of those who would have to struggle to pass the test. An advantage of isometric strength testing is the risk of injury is minimal (NIOSH 1977).
- **Specificity Of Testing.** Dynamic work sample tests, by their nature, are task specific. While a 75-pound floor to knuckle-height lift test provides evidence of the person's capacity to lift that weight, it does not provide valid information about the person's capacity to do other demanding tasks such as generating push or pull force, or shoveling dirt.
- **Test Time.** Dynamic work sample tests can be difficult to set up and time consuming to administer.

8.3 Isometric Strength Correlates with Dynamic Strength

Can isometric strength predict dynamic strength? While some say no, both logic and research say otherwise. Provided in this section are several sources of scientific evidence documenting the strong relationship between isometric and dynamic strength.

8.3.1 Correlations: Isometric and 1-RM

The purpose of a controlled laboratory study completed by Laughlin (1998) was to examine the relationship between closed-kinetic isometric and dynamic leg strength. A sample of 57 healthy, female athletes was administered isometric and isotonic leg strength tests. A Cybex leg press machine was used to test the athletes' maximum isotonic leg strength (1-RM). Both the dominant and non-dominant legs were tested. The Cybex unit was also used to measure dominant and non-dominant isometric strength at 30, 60, and 90° knee flexion.

Table 19 gives the results of the study. The correlations between the isometric and isotonic strength tests were very high. The coefficients ranged from 0.91 to 0.94. These high correlations were and should be expected because the test positions were duplicated, thereby increasing the probability that the isometric and isotonic tests measured the strength of the same muscle groups. These data showed that the type of contraction does affect the measurement of strength. Quite simply, strength is strength, and it is much easier and safer to measure isometric strength than dynamic strength.

TABLE 19. The Pearson product-moment correlations between static and dynamic leg strength (Laughlin, 1998).

ISOMETRIC TEST	ISOTONIC TEST	
	DOMINANT LEG	NON-DOMINANT LEG
90° Knee Flexion	.94	.91
60° Knee Flexion	.93	.91
30° Knee Flexion	.93	.94

8.3.2 Correlations: Isometric and Dynamic Work Sample Tests

Preemployment research completed at the University of Houston conclusively showed that isometric strength tests predict dynamic work sample test performance. Table 20 gives a summary of these results showing that isometric strength is correlated with dynamic work sample tests. The correlations range from a low 0.63 for a 50-pound materials transport test, to a high of 0.91 for a dynamic isokinetic test.

TABLE 20. Correlations between the sum of isometric strength and dynamic simulated work sample tests.

REFERENCE WORK	WORK SAMPLE TEST	TYPE OF TEST	R_{XY}
Jackson et al. 1991	Shoveling Coal	Dynamic - Endurance	0.71
Jackson et al. 1991	50-pound Bag Carry	Dynamic - Endurance	0.63
Jackson & Osburn 1983	70-pound Block Carry	Dynamic - Endurance	0.87
Jackson & Osburn 1983	One-arm Push Force	Isokinetic - Peak Torque	0.91
Jackson et al. 1992	Valve-Turning	Dynamic - Endurance	0.83
Jackson et al. 1993	Box Transport	Dynamic - Endurance	0.76
Jackson et al. 1993	Moving Document Bags	Dynamic - Endurance	0.70

A limitation of work sample tests is their specificity. The test is designed to measure a specific work task. In contrast, the correlations proved in Table 20 show that the PWC/FC isometric strength test can be generalized to a wide variety of work tasks. They validly predict performance on a wide variety of dynamic work tasks.

8.3.3 Correlations: Strength vs. Firefighting Work Sample Test

Work sample tests are commonly used to select firefighter applicants. The test is often involve completing physically demanding tasks required of firefighters. Examples of common firefighter work sample test items (Davis, Dotson, O'Connor & Confessore 1992) are:

1. **Stair Climb.** Carry a 58-pound hose bundle up 5 flights of stairs.
2. **Hoseline Drag.** Drag a 1.75-inch charged hose 100 feet.
3. **Rescue Dummy Drag.** Lift and drag a 175-pound dummy 100 feet.
4. **Smoke Extractor Carry.** Lift and transport a 47.5-pound fan a distance of 150 feet.
5. **Kieser Force Machine.** Repeated pounding of an object with a sledge hammer until it was moved a specified distance. This simulated a forced entry into a building.

The results of a recent preemployment study (Jeanneret & Associates, 1999) showed that isometric strength was correlated with firefighter work sample test performance. The objective of the test was to complete the five firefighter items as quickly as possible, but in a controlled manner (i.e., running was not permitted). The firefighter's score on the work sample test was the elapsed time it took to complete all five parts of the test. The firefighter test was administered to 94 male and 31 female firefighters. In addition to the work sample test, the firefighter's endurance was tested with the 1.5-mile run and the non-exercise VO_{2max} test (Baumgartner & Jackson 1999). The PWC/FC isometric strength tests measured their strength. The data analysis showed that firefighter work sample test performance was more highly correlated with strength than endurance. Table 21 gives the product-moment correlations between the isometric strength and endurance tests and the firefighter test.

TABLE 21. Product-moment correlations between firefighter work-sample test performance and strength and endurance tests.

TEST	CORRELATION*
Arm Lift	-.80
Shoulder Lift	-.72
Torso Pull	-.61
Leg Lift	-.61
1.5-Mile Run	.60
Non-Exercise VO_{2max}	-.66

Since the firefighter test was a timed test, a low score on the test represented a better performance. The negative correlations in Table 21 show that firefighter test performance was dependent upon strength and endurance.[1] The most valid indicator of firefighter test performance was the combination of strength and endurance. The multiple correlation between firefighter test performance and the multivariate combination of isometric arm strength and 1.5-mile time was high, 0.86.

1. The 1-5 mile run was a timed test that firefighter test performance was dependent upon endurance.

8.3.4 Function of Strength on Maximum Acceptable Weight Load

Dempsey and associates (Dempsey, 1998) examined the relationship between types of strength and maximum acceptable weight load (MAWL). Strength was measured with isometric, isokinetic, incremental lifting, and power tests. The method used by Snook (Snook & Ciriello, 1991) was used to measure MAWL. This was a psychophysical method in which the subject selected a weight load for a frequency of one lift in eight hours. All types of strength were significantly related with MAWL.

The correlations ranged from 0.84 for the power measure to 0.50 for the incremental lifting test. A conclusion reached by Dempsey and associates was that dynamic tests should be used instead of isometric tests because the correlation was the highest for the dynamic power test. An examination of the correlations among the nine strength tests showed that all were correlated with each other. A limitation of the study was that only 25 male subjects were tested. It is likely that the differences between the lifting and strength test correlations are due to chance. To examine this more closely, the correlation matrix published by Dempsey et al. was analyzed by factor analysis (SAS, 1998). The goal was to determine if all tests were a function of a common source of variance. Table 22 gives these results.

TABLE 22. Factor analysis of strength data published by Dempsey et al. (1998)

TEST	TYPE OF STRENGTH	FACTOR LOADING
Isometric 15	Static	.70
Isometric 75	Static	.83
Isokinetic 0.1*	Dynamic	.92
Isokinetic 0.2	Dynamic	.90
Isokinetic 0.4	Dynamic	.93
Isokinetic 0.6	Dynamic	.89
Isokinetic 0.8	Dynamic	.90
Incremenhtial Lifting	Dynamic	.70
Power	Dynamic	.87
MAWL	Psychophysical	.83

*Height of lift position. **Speed of movement.

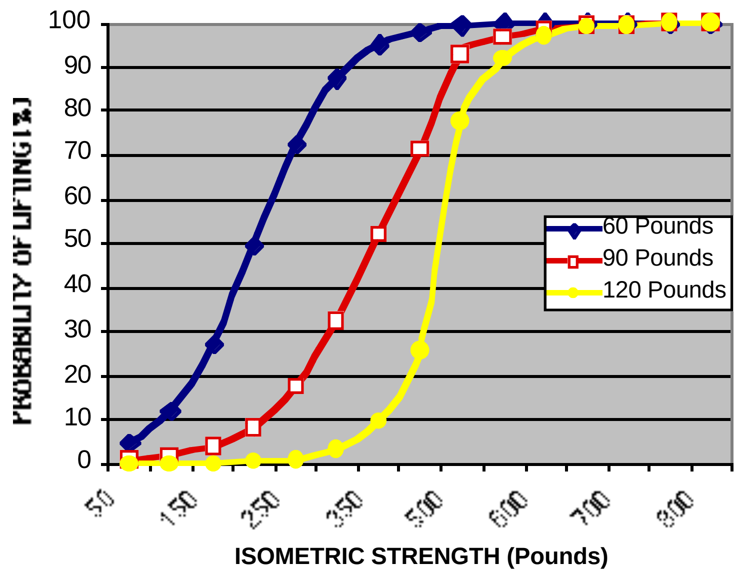
The factor analysis revealed that all nine strength tests and the psychophysical MAWL test produced a single factor that accounted for 72.2% of the total variance. This demonstrated psychophysical lift capacity was a function of a common strength factor consisting of static and dynamic muscle action. This is consistent with published data (Jackson, Borg, Zhang, Laughery, & Chen, 1997) showing that isometric strength was significantly correlated with psychophysical lift capacity measured with Borg's CR10 scale and supports the use of isometric strength tests to measure psychophysical lift capacity.

8.3.5 Isometric Strength and Maximum Lift Capacity

A common work sample test is a pass/fail dynamic lift (Jackson, 1993; 1998). The work sample test simply determines if a person can lift the load in a manner required on the job. When a work task is scaled as a categorical variable, as in this case, logistic regression analysis (Hosmer & Lemeshow, 1989) provides a statistical method of defining the level of strength required to complete the task.This regression model not only determines if strength is significantly related with lift capacity, but also estimates the probability that an individual with a given level of strength would be able to complete the lift.

A work sample test used in one of our study's was to lift an object from the floor and place it on a table (Jackson, 1998). The test simulated lifting an industrial valve and placing it on the bed of a truck. The work sample test involved several weight loads that became progressively heavier. If the subject was able to lift a load, he/she continued to the next heavier weight and continued until a lift was either failed or the heaviest load was lifted. Figure 14 shows the logistic probability curves for three lift loads: 60, 90, and 120 pounds. These data show two trends. First, as the strength of the lifter increased, the more likely the load can be lifted. Second, the isometric strength requirements increase as the weight load of the dynamic task increases.These results not only document the relationship between isometric strength and dynamic lift capacity, but also illustrate the ergonomic principle of matching the worker to the task.Stronger individuals are needed to complete the heavier lifts.

FIGURE 14. Logistic probability curves showing the probability of lifting a load for levels of isometric strength. These curves show that dynamic lift tasks can be estimated from static strength.



9.0 UNIVERSITY OF HOUSTON PREEMPLOYMENT STUDIES

Provided in this section is an overview of the methodology used to complete the University of Houston employment studies. Legal, ergonomic, worker safety and productivity issues were forces that led to the initiation and rise in preemployment research. These validation studies provided the scientific foundation of the PWC/FC Evaluation System. The general research methodology is summarized next.

9.1 Research Methods

The research methods involved three general steps.The first and essential component of research designed to validate an employment test is to conduct a task analysis. A legal requirement of a valid preemployment test is that the test should measure important job tasks and the test must be job-related (EEOC, 1978; EEOC, 1991). The Civil Rights Act of 1964 precludes discrimination based on race, color, religion, national origin, and sex. Additionally, the Americans with Disabilities Act of 1990 prevents an employer from rejecting an applicant because of a disability unless the disabled person is not able to do the job. The task analysis provides these necessary data.

The task analysis defines the demands of the job. Once this was known, the second step was to complete a validation study. This involved determining if the strength tests were correlated with simulated work tasks. These data not only furnished validation evidence, but also provided empirical models for defining the level of strength required by the task. This produced an objective means of defining a physiological cut-score.

9.1.1 Task Analysis

While it is possible to conduct a task analysis in many different ways, our research followed five important, interrelated steps (Jackson, 1994).

1. Job supervisors and incumbents were interviewed to gain a general understanding of the physically demanding work tasks.
2. Using the interview data, questionnaires were developed for each essential work task. It was not uncommon to develop questionnaires with over 100 different tasks. After pilot testing, the questionnaire was administered to workers who did the job. The workers rated each work task in terms of how often the task was done (frequency) and its level of physical demand (effort). APPENDIX C shows an example of a task questionnaire with sample items from the three work families.
3. The frequency and effort data are used to identify the physically demanding work tests.
4. The physically demanding tasks are then biomechanically analyzed to quantify the task's level of demand. The types of data collected during the biomechanical analysis are data such as:
   - The height that objects were lifted.
   - The weight of the object that was lifted or transported.
   - The forces required to open and close valves and move objects (e.g., push containers full of freight).

- The methods used by workers to perform the task. Often the work environment makes the task more difficult (e.g., a valve in an awkward position).
- The use of equipment that may affect task difficulty (e.g., valve wrench or "cheater" that increases the length of the lever).

The task analysis data not only identified the physically demanding tasks of a job, but also showed that industrial physically demanding tasks can be categorized into three major work families. These have be described in another section of this report. The PWC/FC Evaluation System uses these three work families as a model for validating the isometric strength tests.

9.2 Validation Research Methods

Once the physically demanding tasks were identified, the following steps were taken to complete the validation study.

1. The task analysis data were used to develop work sample tests that simulated the work task. Care was taken to duplicate the work environment, methods, and special equipment used by workers to do the work.
2. The work sample tests were pilot tested and revised to insure that they duplicated the work.
3. The isometric strength and work sample tests were administered to samples of test subjects. The subjects tested typically included job incumbents and physically fit college students who were paid to participate in the study. College students were used for two important reasons. First, there was typically a shortage of female job incumbents and the female college students augmented the female sample. Second, the job incumbents normally do the work on a daily basis and for this reason can do the work. In contrast, the college students are more likely not able to do the work. This provided samples of subjects who could and could not meet the demands of the task and helped in the development of physiologically sound cut scores.
4. The data were analyzed with correlation and regression statistical methods. Correlation provided the validity evidence supporting the use of the isometric strength tests. The regression models provided the means of defining the level of strength needed to do the work demanded by the task. These data are provided in the next sections of this manual.

9.2.1 Cut Scores

After completing the validation study, the next, difficult step is to set a cut score. The cut score is the test score that an applicant must obtain to be considered for the job. The Uniform Guidelines merely specifies that cut scores should be reasonable and consistent with normal expectations of acceptable proficiency within the work force (EEOC, 1978). The consensus in the professional literature is that there is no single method of determining a cut score that is optimal in all situations (Cascio, Alexander, & Barrett, 1998).The decision of where to set a cut score for a physical ability preemployment test should be a business decision that not only depends upon the available labor pool, but other factors such as desired level of work productivity, worker safety, and level of adverse impact.

The primary concern when setting a cut score is to find the degree that the test correctly classifies candidates (Cascio et al., 1998; Landy, 1992). The cut score should be based on a rational process and valid selection system that is flexible and meets the needs of the organization. Based on legal, historical, and professional guidelines, Cascio and associates (Cascio et al., 1998) offer several recommendations. The cut score should be based upon the results of the job analysis. The validity and job-relatedness of the testing procedure are crucial. The cut score should be sufficiently high to ensure minimally accepted job performance. The performance level associated with a cut score should be consistent with the normal expectations of acceptable proficiency within the work force. Lastly, a warranted concern is to consider the utility of the decision process (Hunter, Schmidt, & Hunter, 1979). Utility in this context concerns the cost savings for eliminating unqualified applicants (Arnold, Rauschenberger, Soubel, & Guion, 1992)

The strategies used to set cut scores evolved largely from preemployment studies using psychological paper and pencil tests. In physical testing, a tradition of work physiology and ergonomics is to match the worker to the physiological demands of the task. Maximum oxygen uptake and strength are the physiological variables often used to evaluate a worker's capacity. Biomechanical and psychophysical data used to define "safe" material handling tasks provide another source of data to define cut scores for industrial jobs.Regression models provide the empirical means of defining cut scores based on the applicants' physiological capacity.

9.3 Validity Evidence: Materials Lifting Tasks

Materials lifting is one of the most common industrial tasks. Many companies have a lift requirement as a condition of employment. Materials lifting tasks involve lifting objects such as boxes and bags to various heights, at various work rates. Workers must assume a variety of postures to do the work (NIOSH, 1981; Waters et al., 1993). This work family has been the focus of major ergonomic research because materials lifting tasks are the principal cause of industrial back injuries (Snook et al., 1978). These important findings are summarized next.

9.3.1 Materials Lifting and Back Injury

About 80% of Americans experience a low back disorder at some time in their lives. In 1988, the total compensationable cost for low back disorders in the United States was $15.3 billion, and 16.4% of the workers compensation claims of a major insurance company were for low back disorder (Snook, 1991). Data from the Bureau of Labor Statistics show that physically demanding tasks have the highest incidence of back injuries. The highest incidence ratios (per 100 claims) were laborers (12.3), garbage collectors (11.1), warehousemen (9.3), miscellaneous mechanics (5.6), and nursing aides (3.6) (Klein, Jensen, & Sanderson, 1984). All these occupations have a substantial lifting requirements.

The low back injury rate associated with physically demanding lifting tasks has motivated ergonomic researchers to search for "safe" lift standards for industrial populations. NIOSH published equations (NIOSH, 1981; Waters et al., 1993) in an effort to define "safe" lift standards for industrial populations. The psychophysical approach is a principal method used to define "safe" lift standards. It is based on worker perception of lift difficulty. This psychophysical research has led to the publication of maximum acceptable lifting levels and work rates for industrial populations (Ciriello & Snook, 1983; NIOSH, 1981; Snook, 1978; Snook & Ciriello, 1974; Snook & Ciriello, 1991; Snook & Irvine, 1969; Snook, Irvine, & Bass, 1970; Waters et al., 1993). An acceptable level was defined psychophysically by having the subject adjust the weight in a box until they found a weight that allowed them to work “without straining themselves.”

Psychophysically demanding lift loads increase the risk for low back injury. Snook et al. (1978) completed a major retrospective, epidemiological study examining factors related to low back insurance claims. They discovered that a worker was three times more susceptible to low back injury if he or she was lifting loads that were acceptable to less than 75% of the industrial population. They reported that the injury rate associated with materials handling could be reduced by 67% if workers lifted just those loads defined to be psychophysically acceptable for the industrial population, i.e., ≥75% of workers who could lift the load without undue strain. Of interest, they also discovered that back x-rays did not constitute an effective preemployment test and “teaching workers how to lift properly” did not lower the risk of back injury.

Keyserling et al. (Keyserling & al., 1980; Keyserling, Herrin, & Chaffin, 1980) showed that workers with strength capacities below that demanded by the work task were at a higher risk of both arm and back injury than those with sufficient strength to do the task. While Keyserling and associates did not use psychophysical methods, they did examine work tasks in relation the worker’s maximum strength capacity. Their data showed that the risk of injury increased as the worker approached their maximum strength capacity. The Snook and Keyserling studies are consistent because psychophysical ratings are a relative measure. They reflect a level of effort in relation to their maximum capacity (Borg, 1998; Resnik, 1995).

9.3.2 PWC/FC Lifting Model

Psychophysical ratings define maximum acceptable lift loads for industrial populations. Several variables affect these ratings, the most prominent being gender, load weight, lift rate, and type of lift. It well known that strength and endurance vary greatly among individuals (Ayoub, 1982; Hoffman, Stouffer, & Jackson, 1979; McArdle et al., 1991; Snook et al., 1978; Wilmore & Costill, 1994) consequently, there is no single maximum weight that is acceptable for everyone. Snook and Ciriello (Snook & Ciriello, 1991) considered these factors and defined maximum acceptable psychophysical lift standards for populations of male and female workers.

The initial work in defining psychophysical safe lift loads was for industrial populations (NIOSH, 1981; Snook, 1978; Snook & Ciriello, 1974; Snook & Ciriello, 1991; Snook & Irvine, 1969; Snook et al., 1970; Waters et al., 1993). A limitation of this approach is that it does not recognize the variability in physical work capacity among workers. Hidalgo and associates (1997) point out that a major limitation of the most recent NIOSH equation (Waters et al., 1993) is that it “... was designed to avoid gender-, age- or fitness-based recommended weight limits due to consideration of the Equal Employment Opportunity legislation and the Americans with Disability Act.” Hidalgo and associates developed a comprehensive lifting model that considers differences in physical ability of workers. Results from this study are consistent with published data (Jackson, Borg, Zhang, Laughery, & Chen, 1997), showing an inverse relationship between strength, fat-free weight, and psychophysical ratings of lift difficulty. Weaker people, those with less fat-free weight, psychophysically rate lifts more difficult than their stronger counterparts, and are also less able to lift heavier loads (Hodgdon, 1992; Jackson et al., 1997; Vogel & Friedl, 1992).

In order to account for the individual differences in physical work capacity, investigators (Chin, 1995; Hidalgo, 1997; Jackson et al., 1997; Karwowski, 1996; Resnik, 1995) have used Borg's rating of perceived exertion scales (Borg, 1998) to define an individual's psychophysical lift capacity. This approach was used to develop the materials lift standards of the PWC/FC Evaluation system. Ergonomic equations (Waters et al., 1993) and data from several sources (Bliss, 1998; Jackson, 1998; Jackson et al., 1997; Sekula, 1999) were used to define the PWC/FC lift standards. The methods used to develop these individual standards were as follows.

1. Subjects were administered a floor-to-knuckle height lift test. The dynamic lift test involved lifting several objects that became progressively heavier.
2. After each lift, the subject rated lift difficulty using Borg's CR-10 scale (Borg, 1998).
3. The subject continued until the maximum load was lifted or the load was too heavy for the lifter.
4. Use of the CR-10 rating was the dependent variable and the lift weight was the independent variable; power functions[1] were fitted to each individual's data (SAS, 1998). This provided a model that defined the individual's psychophysical lift profile.
5. In addition to the dynamic work sample lift test, each subject's isometric strength was measured following the methods outlined in this manual.

The goal of this research was to develop a statistical model to estimate the individual's psychophysical lift rating based on their strength and the lift load. Multiple regression was used to develop the model. The dependent variable was the CR-10 rating while the independent variables were the weight load for the associated CR-10 rating and the subject's isometric strength. One CR-10 rating and the associated lift weight was randomly selected for each subject. Multiple regression was used to develop a model. The database used for this analysis included 961 men and women tested in our laboratory. This analysis yielded an accurate multiple regression model (R = 0.82, SEE = 1.6 CR-10 units). Table 23 illustrated the model. Provided are the estimated CR-10 ratings for selected lift weights and levels of isometric strength. These data show three expected trends.

- As lift load increases, CR-10 ratings increase, i.e., the lift becomes more difficult.
- There is an inverse relationship between CR-10 rating and strength. For any of the six lift loads, higher levels of strength are associated with lower CR-10 ratings.
- By knowing the person's isometric strength and the lift weight, the individual's psychophysical lift difficulty can be determined.

These data were used to define the PWC/FC Evaluation System lift levels. Data from several sources (Hidalgo, 1997; Jackson et al., 1997; Karwowski, 1996; Sekula, 1999) and ergonomic models (NIOSH, 1981; Resnik, 1995; Waters et al., 1993) were used to establish the standards. The standards are:

1. You are directed to other sources (Borg, 1998; Jackson et al., 1996a) for discussion and example of the use of power functions with CR-10 ratings.

- **LEVEL III:** Lift weights with CR-10 rating >7, which represents a lift load that a subject would not be likely to lift. If able to lift the weight, the lift would be a struggle for the lifter.
- **LEVEL II:** Lift weights with a CR-10 rating ≤ 7.0.
- **LEVEL I:** Lift weights with a CR-10 rating ≤4.0.

TABLE 23. Estimated CR-10 Psychophysical rating for selected levels of isometric strength and lift loads. Borg's CR-10 scale is shown for reference.

0	Nothing at All	ΣFOUR	LIFT LOAD IN POUNDS				
0.5	Extremely Light		25	50	75	100	125
1	Very Light	100	3.1	5.9	8.6	>10.0	>10.0
2	Light	175	2.5	5.1	7.7	>10.0	>10.0
3	Moderate	250	1.9	4.3	6.8	9.2	>10.0
4	Somewhat Heavy	325	1.3	3.6	5.9	8.1	>10.0
5	Heavy	400	<1.0	2.8	4.9	7.1	9.2
6		475	<1.0	2.1	4.0	6.0	8.0
7	Very Heavy	550	<1.0	1.3	3.1	5.0	6.8
8		625	<1.0	<1.0	2.2	3.9	5.6
9		700	<1.0	<1.0	1.3	2.8	4.4
10	Extremely Heavy	775	<1.0	<1.0	<1.0	1.8	3.2

9.4 Validity Evidence: Maximum Force Tasks

There are several industrial tasks that require the worker to exert a brief, forceful contraction. The maximum force tasks of the PWC/FC Evaluation System are divided into two family members: 1) Push/Pull tasks: and 2) Breaking tasks.

9.4.1 Push/Pull Tasks

Many tasks require workers to exert maximum force by pushing or pulling a heavy object (Jackson et al., 1993). Examples are “tipping” a heavy 55-gallon drum or moving a container or dolly full of freight. In the push or pull position, the hands are placed on the object being moved at about waist to chest height. The force is not only generated by the involved muscle groups, but also the worker's body weight. Some force can be generated by “leaning” into, or “pulling away” from, the object being pushed or pulled.

The computer report gives an estimate of the individual's maximum capacity to generate push and pull force (pounds). The force required to do the push/pull task can be objectively determined by measuring the peak force required to do the task. Matching the person to the task involves comparing the person's push and pull scores with the peak force required to do the task. Table 24 gives the correlations between isometric strength and push/pull force capacity.

9.4.2 Breaking Tasks

Breaking tasks require a worker to apply force to a tool (e.g., valve wrench, pipe wrench, etc.) to “break” a nut or “crack” an industrial valve. The capacity to apply force varies by body position. In some work environments, only the upper body can be used to generate torque. An example would be applying force to a valve wrench in a horizontal direction while in a standing position. For other tasks, the work environment allows the worker to apply force to a wrench with both the upper body and legs. An example would be being able to lift up on a wrench that is below waist height. This would allow the person to bend their legs and use the leg muscles to generate force.

The length of the lever used influences the amount of breaking torque the individual can generate. For example, a common practice is to put a “cheater-bar” on a wrench. This increases the length of the lever (i.e., the load-moment arm) and increases the person’s capacity to generate torque. To illustrate, if the person applies 100 pounds of force to a wrench with a one foot load-moment arm, 100 foot-pounds of torque are generated. But if a “cheater” is used and it increases the load-moment arm to three feet, the 100 pounds of force would generate 300 foot-pounds of torque. The PWC/FC Evaluation System normalized this by expressing the person’s breaking torque in foot-pounds.

The PWC/FC Evaluation System’s computer-generated report estimates the individual’s upper body and total body torque (foot-pounds) generation capacity (Jackson, 1998). Table 24 gives the correlations between isometric strength and upper and total body torque production capacity.

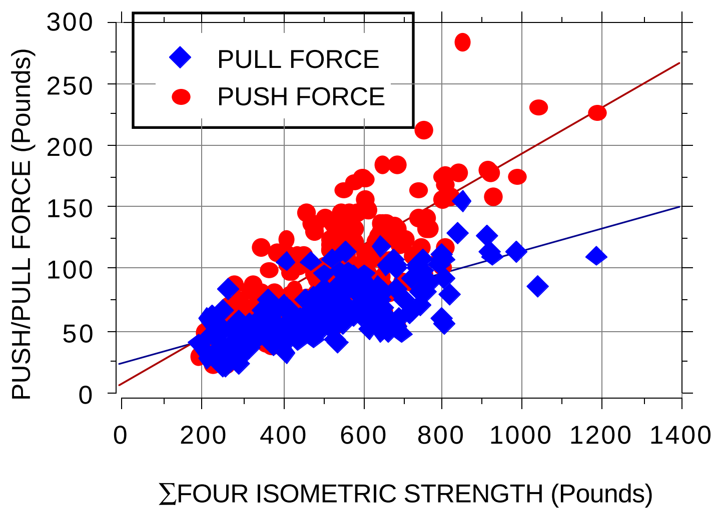
TABLE 24. Correlations between the sum of isometric strength* and simulated push/pull and breaking work sample tests.

REFERENCE WORK	WORK SAMPLE TEST	WORK FAMILY MEMBER	R_{XY}
Jackson 1986	Push Force	Push Force	0.86
Jackson et al. 1993	Push Force	Push Force	0.78
Jackson 1986	Pull Force	Pull Force	0.78
Jackson et al. 1993	Pull Force	Pull Force	0.67
Jackson et al. 1998	Valve Cracking	Total Body Breaking Capacity	0.87
Jackson et al. 1998	Valve Cracking	Upper Body Breaking Capacity	0.84

9.4.3 Maximum Force Cut Scores

The correlations between the isometric strength tests and the maximum force work sample tests are high, ranging from 0.67 to 0.87. These data were used to develop regression equations for estimating the amount of force the person was able to generate. Figures 15 and 16 show the regression analysis for push/pull tasks (Jackson et al., 1993) and upper body and total body breaking capacity (Jackson, 1998). As these figures show, an individual's capacity to generate force varies by position. A person is able to generate more push force than pull force. The total body breaking capacity exceeds upper body breaking capacity because the person could use their legs with the total body breaking capacity work sample test. These regression models provide an objective, empirical model to define the level of strength needed to generate a level push/pull force and breaking torque. The PWC/FC Evaluation System computer-generated report used these models to estimate the person's capacity for maximum force tasks.

FIGURE 15. Regression models for estimating push and pull force from isometric strength.

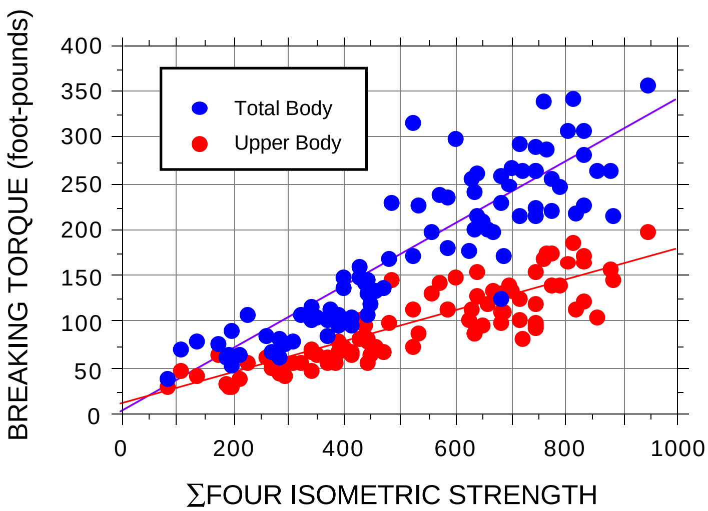


9.5 Validity Evidence: Endurance Work Tasks

Endurance work tasks are those that involve repetitive, continuous work for time periods lasting 15 minutes or longer. How can isometric strength tests validly measure endurance tasks? The common link is fat-free weight. The most valid measure of endurance capacity is $VO2_{max}$, which can be expressed in either absolute or relative terms. Absolute $VO2_{max}$ is scaled in either liters or milliliters of oxygen consumed per minute (L/min or ml/min). Absolute $VO2_{max}$ is not only a function of the body's oxygen transport system, but also the person's fat-free weight, or more correctly, their muscle mass. The absolute $VO2_{max}$ of bigger, stronger individuals exceeds that of smaller, weaker people. Relative $VO2_{max}$ is expressed by milliliters of oxygen, per kilogram of body weight, per minute (ml/kg/min). Relative $VO2_{max}$ is normalized for body weight. It is calculated by dividing absolute VO2 (ml/min) by body weight. The correlation between relative $VO2_{max}$ and fat-free weight tends to be low, near zero, but it is high for absolute $VO2_{max}$.

Relative $VO2_{max}$ is used to evaluate one's physical fitness and is an important endurance variable involving moving one's own body weight. An industrial example would be climbing stairs. You are directed to other sources (Baumgartner & Jackson, 1999; Ross & Jackson, 1990) for a more detailed discussion.

FIGURE 16. Regression models for estimating breaking torque from isometric strength. Total body breaking torque is higher than upper body because the legs can be used with total body.



The correlation between absolute endurance and strength tests is high. DeVries (1980; 1994) reported that these correlations exceed 0.90. The physiological reason can be easily illustrated with a weight lifting example. Assume an exercise is to lift a 50-pound weight as many times as possible. If a person's maximum lift capacity is only 60 pounds, the intensity of the lift would be 83% of their maximum capacity (50/60 = 0.83). In contrast, if the lift capacity of a stronger person was 150 pounds, the work intensity for this person would only be 33%. There is a direct relationship between fatigue and work intensity. The closer one is to their maximum capacity, the sooner fatigue (i.e., absolute VO_{2max}) is reached.

Industrial endurance work tasks are absolute endurance tasks. A 50-pound bag is the same for everyone. The power output required to close an industrial valve is the same for strong or weak workers. Thus, the linkage between strength and absolute endurance is the power output or intensity of the work task. Bigger, stronger individuals are able to work at a lower percentage of their maximum capacity than smaller, weaker individuals. The task is easier for the stronger worker.

The scientific unit of measurement that expresses endurance working capacity is oxygen uptake in liters per minute (L/min) or energy expenditure expressed in kilocalories per minute (kcal/min). About 4.8 kilocalories are expended for each liter of oxygen a person consumes (McArdle et al., 1991). The PWC/FC Evaluation System computer-generated report estimates the person's total body and upper body endurance energy expenditure capacity. These estimates come from preemployment studies in which VO_{2max} was either measured (Jackson & Osburn, 1983) or estimated (Jackson et al., 1993).

Table 25 gives the correlations between endurance work sample tests and isometric strength. While these validity coefficients are slightly lower than the maximum force coefficients, they are reasonably high. Of interest, in one study (Jackson & Osburn, 1983) metabolic VO_{2max} was measured. The correlation between shoveling and isometric strength tests was higher than the correlation found with measured arm VO_{2max}.

TABLE 25. Correlations between the sum of isometric strength and simulated work sample tests.

REFERENCE WORK	WORK SAMPLE TEST	WORK FAMILY MEMBER	R_{XY}
Jackson et al. 1991	Shoveling Coal	Upper Body Endurance	0.71
Jackson et al. 1992	Valve-Turning	Upper Body Endurance	0.83
Jackson et al. 1993	Moving Document Bags	Upper Body Endurance	0.70
Jackson et al. 1993	Box Transport	Total Body Endurance	0.76
Jackson et al. 1991	50-pound Bag Carry	Total Body Endurance	0.63
Jackson & Osburn 1983	70-pound Block Carry	Total Body Endurance	0.87

10.0 REFERENCES

10.1 University of Houston Preemployment Studies

Jackson, A. S. (1986). Validity of isometric strength tests for predicting work performance in offshore drilling and producing environments. Houston: Shell Oil Company, 1986. Houston: Shell Oil Company.

Jackson, A. S. (1987). Validity of isometric strength tests for predicting work performance of refinery workers. Houston: Shell Oil Company.

Jackson, A. S. (1994b). Prediction Of Torso Lift Strength From Torso Pull. Houston: University of Houston.

Jackson, A. S., Osburn, H. G., Laughery, K. R., Sekula, B. K. (1998b). Revalidation of Methods for Preemployment Assessment of Physical Abilities at Shell Western Exploration and Production, Inc., and CalResources LLC. Houston, TX: University of Houston.

Jackson, A. S. (July, 1998). Analysis of Physically Demanding Tasks of Consolidated Freightways: Indianapolis Terminal (Technical Report 1-CF-98). Houston, TX: The Author.

Jackson, A. S., & Osburn, H. (1983). Preemployment physical test development for coal mining technicians. Technical Report to Shell Oil Co. Houston: Shell Oil Company.

Jackson, A. S., Osburn, H. G., & Laughery, K. R. (1984). Validity of isometric strength tests for predicting performance in physically demanding jobs. *Proceedings of the Human Factors Society 28th Annual Meeting,* 28, 452-454.

Jackson, A. S., Osburn, H. G., Laughery, K. R., & Vaubel, K. P. (1990b). Validation of Physical Strength Tests for the Texas City Plant - Union Carbide Corporation. Houston: Center for Psychological Services.

Jackson, A. S., Osburn, H. G., Laughery, K. R., & Vaubel, K. P. (1992b). Validity of isometric strength tests for predicting the capacity to crack, open and close industrial valves. *Proceedings of the Human Factors Society 36th Annual Meeting,* 1, 688-691.

Jackson, A. S., Osburn, H. G., Laughery, K. R., & Young, S. L. (1993a). Validation of Physical Strength Tests for the Federal Express Corporation. Houston: Center of Applied Psychological Services, Rice University.

Jackson, A. S., Osburn, H. G., Laughery, K. R., Young, S. L., & Zhang, J. J. (1994). Patient Lifting Tasks at Methodist Hospital. Houston: Center of Applied Psychological Services, Rice University.

Jackson, A. S., Osburn, H. G., & Laughery, S., K.R. (1991a). Validity of isometric strength tests for predicting endurance work tasks of coal miners*. Proceedings of the Human Factors Society 35th Annual Meeting,* 1, 763-767.

Jackson, A. S., Osburn, H. G., Laughery Sr., K. R., & Vaubel, K. P. (1991b). Strength demands of chemical plant work tasks. *Proceedings of the Human Factors Society 35th Annual Meeting,* 1, 758-762.

Jackson, A. S., Zhang, J. J., Laughery, K. R., Osburn, H. G., & Young, S. L. (1993b). Final Report: Patient Lifting Tasks at Methodist Hospital. Houston: Center of Applied Psychological Services, Rice University.

Jenneretf, P. R., Blakely, B. R., Crawford, M. S., & Jackson, A. S. (1992). Houston Fire Department: Development and Validation of a Physical Ability Test. Houston: Jennerett and Associates.

Laughery, K. R., & Jackson, A. S. (1982). Preemployment physical test development for land production and offshore drilling environments. Houston: Shell Oil Co.

Laughery, K. R., & Jackson, A. S. (1984). Preemployment physical test development for roustabout jobs on offshore production facilities. Lafayette, Louisiana: Kerr-McGee Corp.

Laughery, K. R., & Jackson, A. S. (1987). Preemployment physical test development for stewart, utilities and warehouse jobs. Houston: Center of Applied Psychological Sciences, Rice University.

Laughery, K. R., Jackson, A. S., Sanborn, L., & Davis, G. (1981). Preemployment Physical Test Development for Offshore Drilling and Production Environments. Houston: Employment Services, Head Office Employee Relations, Shell Oil Co.

Laughery, K. R., Jackson, A. S., Sanborn, L., & G.A Davis. (1979). Preemployment physical test development for offshore drilling and production environments. Technical Report to Shell Oil Co. Houston: Shell Oil Company.

Laughery, K. R., Osburn, H. G., Jackson, A. S., Hogan, J. L., & Hayes, T. L. (1986). Physical abilities and performance tests for coal miner jobs. Houston: Center of Applied Psychological Sciences, Rice University.

10.2 Jeanneret & Associates, Inc.

Dr. Jackson worked with Jeanneret & Associates on these preemployment studies. The address of Jeanneret & Associates is: 601 Jefferson, Suite 3900, Houston, TX 77002.

Jeanneret & Associates, Inc. (1990). American Gas Association - Physical ability study. Arlington, VA: American Gas Association.

Jeanneret & Associates, Inc. (1991). Development and validation of trooper physical ability and cognitive ability tests. Austin, TX: Texas Department of Public Safety.

Jeanneret & Associates, Inc. (1992). Development and validation of Preemployment physical abilities test. Houston, TX: Houston Fire Department.

Jeanneret & Associates, Inc. (1992). Development and validation of physical abilities test for sheriff’s deputy and detention officer. Houston, TX: Harris County Sheriff’s Department.

Jeanneret & Associates, Inc. (1999). Evaluation of physical ability and written tests for entry-level firefighters. St. Paul, MN: City of St. Paul Fire Department.

10.3 General References

ACSM. (1991). *Guidelines for Exercise Testing and Prescription.* (3rd edition ed.). (Vol. 4th). Philadelphia: Lea and Febiger.

ACSM. (1993). *ACSM's Resource Manual For Guidelines for Exercise Testing and Prescription.* (2nd ed.). Philadelphia: Lea & Febiger.

Arnold, J.D., Rauschenberger, J.M., Soubel, W.G., and Guion, R.M. Validation and utility of a strength test for selecting steelworkers. *Journal of Applied Psychology* 67:588-604, 1982.

Åstrand, P.-O., & Rodahl, K. (1986). *Textbook of Work Physiology.* (3rd ed.). New York: McGraw-Hill.

Ayoub, M. A. (1982). Control of manual lifting hazards: III. Preemployment screening. *Journal of Occupational Medicine,* 24, 751-761.

Ayoub, M. M., Mital, A., Bakken, G. M., Asfour, S. S., & Bethea, N. (1980). Development of strength and capacity norms for manual materials handling activities: The state of the art. *Human Factors,* 22, 271-283.

Baumgartner, T. A., & Jackson, A. S. (1999). *Measurement for Evaluation in Physical Education and Exercise Science.* (6th ed.). Dubuque: Wm. C. Brown.

Blair, S. N., Kohl III, H. W., Paffenbarger Jr., R. S., Clark, D. G., Cooper, K. H., & Gibbons, L. W. (1989). Physical fitness and all-cause mortality: A prospective study of health in men and women. *Journal of the American Medical Association*, 262, 2395-2401.

Blair, S. N., Kohl III, H. W., Barlow, M. S., Paffenbarger Jr., R. S., Gibbons, L. W., & Macera, C. A. (1995). Changes in physical fitness and all-cause mortality: A prospective study of healthy and unhealthy men. *Journal of the American Medical Association,* 273(14), 1093-1098.

Bliss, G. (1998). The Effect of Physical Working Capacity on Psychophysically Defined Lifting Limits. Unpublished M.S., University of Houston, Houston, TX.

Borg, G. (1998). *Borg's Perceived Exertion and Pain Scaling Method*. Champaign: Human Kinetics.

Brooks, G., & Fahey, T. (1984). *Exercise Physiology: Human Bioenergetics and its Applications.* New York: John Wiley and Sons.

Buskirk, E. R., & Hodgson, J. L. (1987). Age and aerobic power: the rate of change in men and women. *Federation Proceedings*, 46, 1824-1829.

Cady, L. D., Bishoff, D. P., O'Connell, E. R., Thomas, P. C., & Allan, J. H. (1979). Back injuries in firefighters. *Journal of Occupational Medicine,* 21, 269-272.

Cady, L. J., Thomas, P., & Karwasky, R. (1985). Program for increasing health and physical fitness of fire fighters. *Journal of Occupational Medicine*, 27, 110-114.

Cascio, W.F., R.A. Alexander, and G.V. Barrett. Setting cutoff scores: Legal, psychometric, and professional issues and guidelines. *Personnel Psychology,* 41:1-24, 1988.

Chin, A., Bishu, R.R., Halbeck, S. (1995). Psychophysical measures of exertion. Are the they muscle group dependent. *Proceedings of the Human Factors Society*, 694-698.

Ciriello, V. M., & Snook, S. H. (1983). A study of size, distance, height, and frequency effects on manual handling tasks. *Human Factors*, 25(473-483).

Davis, P.O., Dotson, C.O., O'Connor, J.S., & Confessore, R.J. (1992). The development of a job-related physical performance test for Saint Paul firefighters. Saint Paul, MN: Saint Paul Fire Department.

Dempsey, P. G., Ayoug, M.M., Westfall, P.H. (1998). Evaluation of the ability of power to predict low frequency lifting capacity. *Ergonomics*, 41, 1222-1241.

deVries, H. A. (1980). *Physiology of exercise for physical education and athletics.* Dubuque, IA: Wm.C. Brown.

deVries, H. A., Housh, T.J. (1994). *Physiology Of Exercise For Physical Education, Athletics And Exercise Science*. (5th ed.). Dubuque, IA: Wm.C. Brown.

Durnin, J. V. G. A., & Passmore, R. (1967). *Energy, Work and Leisure*. London: Heinemann Educational Books, LTD.

EEOC. (1978). Uniform Guidelines on employment selection procedures. *Federal Register*, 43(38289-28309).

EEOC. (1991). Equal employment opportunity for individuals with disabilities: *Final Rule. Federal Register,* 56(144), 29 CRF Parts 1602 and 1627.

Foster, C., Jackson, A. S., & Pollock, M. L. (1984). Generalized equations for predicting functional capacity from treadmill performance. *American Heart Journal*, 107, 1229-1234.

Gettman, L. R. (1993). Chapter 19 Fitness Testing. In ACSM. (Ed.), *Resource Manual for Guidelines for Exercise Testing and Prescription* (2nd Edition ed., pp. 229-246). Philadelphia: Lea & Febiger.

Golding, L. A., Meyers, C. R., & Sinning, W. E. (1989). *The Y's Way to Physical Fitness.* (3 ed.). Chicago: National Board of YMCA.

Hidalgo, J., Genaidy, A., Karwowski, W., Christensen, D., Huston, R., Stambough, J. (1997). A comprehensive lifting model: beyond the NIOSH lifting equation. *Ergonomics*, 40(9), 916-927.

Hodgdon, J. A. (1992). Body composition in the military services: standards and methods. In B. M. Marriott & J. Grumstrup-Scott (Eds.), *Body Composition and Physical Performance: Applications for the Military Services* (pp. 57-70). Washington, D.C.: National Academy Press.

Hoffman, T., Stouffer, R., & Jackson, A. S. (1979). Sex differences in strength. *American Journal of Sports Medicine*, 7, 265-267.

Hogan, J. C. (1991). Chapter 11 Physical Abilities. In M. D. Dunnette & L. M. Hough (Eds.), *Handbook of Industrial and Organizational Psychology* (2nd ed., Vol. 2, pp. 743-831). Palo Alto: Consulting Psychologist Press, Inc.

Hosmer, D. W., & Lemeshow, S. (1989). *Applied Logistic Regression*. New York: John Wiley & Sons.

Hubert, H. B., et al. (1983). Obesity as an independent risk factor for cardiovascular diseases: A 26-year follow-up of participants in the Framingham heart study. *Circulation*, 67, 968-977.

Hunter, J.E., F.L. Schmidt, and R. Hunter. Differential validity of employment tests by race: A comprehensive review and analysis. *Psychological Bulletin,* 86:721-735, 1979.

Jackson, A. S. (1994). Chapter 3 Preemployment Physical Evaluation. *Exercise and Sport Science Reviews*, 22, 53-90.

Jackson, A. S., Beard, E. F., Wier, L. T., Ross, R. M., Stuteville, J. E., & Blair, S. N. (1995). Changes in aerobic power of men ages 25-70 years. *Medicine and Science in Sports and Exercise*, 27, 113-120.

Jackson, A. S., Blair, S. N., Mahar, M. T., Wier, L. T., Ross, R. M., & Stuteville, J. E. (1990a). Prediction of functional aerobic capacity without exercise testing. *Medicine and Science in Sports and Exercise*, 22, 863-870.

Jackson, A. S., Borg, G., Zhang, J. J., Laughery, K. R., & Chen, J. (1996a). Function of physical working capacity on psychophysical lift ratings. July, 1996, pp. 309-314. In A. Mital, H. Krueger, S. Kumar, M. Menozzi, & J. Fernandez (Eds.), *Advances in Occupational Ergonomics and Safety I Proceedings of the XIth Annual International Occupational Ergonomics and Safety Conference*. Zurich, Switzerland,: International Society for Occupational Ergonomics and Safety.

Jackson, A. S., Borg, G., Zhang, J. J., Laughery, K. R., & Chen, J. (1997). Role of physical work capacity and load weight on psychophysical lift ratings. *International Journal of Industrial Ergonomics*, 20, 181-190.

Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition,* 40, 497-504.

Jackson, A. S., & Pollock, M. L. (1985). A practical approach for assessing body composition of men, women, and athletes. *Physician and Sportsmedicine,* 13, 195-206.

Jackson, A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise,* 12, 175-182.

Jackson, A. S., Wier, L. T., Ayers, G. W., Beard, E. F., Stuteville, J. E., & Blair, S. N. (1996b). Changes In Aerobic Power Of Women, Ages 20 To 64 Years. Medicine and Science in Sports and Exercise, 28, 884-891.

Karwowski, W. (1996). Maximum safe weight of lift: A new paradigm for setting design limits in manual lifting tasks based on the psychophysical approach. *Proceedings of the Human Factors Society*, 614-618.

Kasch, F. W., Boyer, J. L., VanCamp, S. P., Verity, L. S., & Wallace, J. (1990). The effect of physical activity and inactivity on aerobic power in older men (a longitudinal study). *The Physician and Sportsmedicine,* 18, 73-81.

Kasch, F. W., Wallace, J. P., & VanCamp, S. P. (1985). Effects of 18 years of endurance exercise on the physical work capacity of older men. *Journal of Cardiopulmonary Rehabilitation*, 5, 308-312.

Keyserling, W. M., et al.(1980). Establishing an industrial strength testing program. *American Industrial Hygiene Association Journal*, 41, 730-736.

Keyserling, W. M., Herrin, G. D., & Chaffin, D. B. (1980). Isometric strength testing as a means of controlling medical incidents on strenuous jobs. *Journal of Occupational Medicine*, 22, 332-336.

Klein, B. P., Jensen, R. C., & Sanderson, L. M. (1984). Assessment of workers' compensation claims for back strains/sprains. *Journal of Occupational Medicine,* 26, 443-448.

Landy, F.J. Alternatives to Chronological Age in Determining Standards of Suitability for Public Safety Jobs: Volume I: Technical Report., The Pennsylvania State University: Center for Applied Behavioral Sciences. 1992.

Laughlin, M. S. (1998). The Relationship Between Isometric and Isotonic Closed Kinetic Chain Leg Strength. Unpublished M.S., University of Houston, Houston.

Leon, A. S. (1989). Effects of physical activity and fitness on health. In N. C. f. H. Statistics (Ed.), Assessing Physical Fitness and Physical Activity in Population-Based Surveys (Vol. DHHS Pub. No. (PHS) 89-1253,). Hyattsville, MD: US Department of Health and Human Services.

Lohman, T. G. (1992). Advances in Body Composition Assessment. Champaign: Human Kinetics Publishers.

Marris, W. S., Fine, L.J., Ferguson, S.A., Walters, T.R. (1999). The effectiveness of commonly used lifting assessment methods to identify industrial jobs associated with elevated risk of low-back disorders. *Ergonomics*, 42, 229-245.

McArdle, W. D., Katch, F. I., & Katch, V. L. (1991). *Exercise Physiology: Energy, Nutrition, and Human Performance.* (3rd ed.). Philadelphia: Lea & Febiger.

NIOSH. (1977). *Preemployment Strength Testing.* Washington: U.S. Department of Health and Human Services.

NIOSH. (1981). *Work Practices Guide for Manual Lifting.* Washington. Washington: U.S. Department of Health and Human Services.

Pollock, M. L., Bohannon, R. L., Cooper, K. H., Ayres, J. J., Ward, A., White, S. R., & Linnerud, A. C. (1976). A comparative analysis of four protocols for maximal treadmill stress testing. *American Heart Journal*, 92, 39-42.

Pollock, M. L., Wilmore, J. H., & S.M. Fox, I. (1984). *Exercise in Health and Disease.* Philadelphia: W.B. Saunders.

Resnik, M. L. (1995). The generalizability of psychophysical ratings in predicting the perception of lift difficulty. *Proceedings of the Human Factors Society*, 679-682.

Ross, R. M., & Jackson, A. S. (1990). *Exercise Concepts, Calculations, and Computer Applications.* Carmel, IN: Benchmark Press.

SAS. (1998). *Statview (Version 5.0)*. Cary, NC: SAS Institute, Inc.

Sekula, B. A. (1999). Application of Borg's CR-10 Psychophysical Scale to Lift Capacity. Unpublished Ed.D, University of Houston, Houston, TX.

Snook, S. H. (1978). The design of manual handling tasks. *Ergonomics*, 21, 963-985.

Snook, S. H. (1991). Low back disorders in industry. Proceedings of the Human Factors Society 35th Annual Meeting, 35(830-833).

Snook, S. H., Campanelli, R. A., & Hart, J. W. (1978). A study of three preventive approaches to low back injury. *Journal of Occupational Medicine*, 20, 478-481.

Snook, S. H., & Ciriello, B. M. (1974). Maximum weights and work loads acceptable to female workers. *Journal of Occupational Medicine,* 16, 527-534.

Snook, S. H., & Ciriello, V. M. (1991). The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics*, 34, 1197-1213.

Snook, S. H., & Irvine, C. H. (1969). Psychophysical studies of physiological fatigue criteria. *Human Factors,* 11, 291-299.

Snook, S. H., Irvine, C. H., & Bass, S. F. (1970). Maximum weights and work loads acceptable to male industrial workers. *American Industrial Hygiene Association Journal*, 31, 579-586.

USDHHS. (1990). Healthy People 2000: National Health Promotion and Disease Prevention Objectives. (DHHS Publication No. (PHS) 91-50212 ed.). Washington D.C.: Department of Health and Human Services.

USDHHS. (1996). Physical Activity and Health: A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Preventing and Health Promotion.

Vogel, J. A., & Friedl, K. E. (1992). Army Data: Body composition and physical capacity. In B. M. Marriott & J. Grumstrup-Scott (Eds.), *Body Composition and Physical Performance: Applications for the Military Services* (pp. 89-104). Washington, D.C.: National Academy Press.

Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics*, 7, 749-766.

Wilmore, J. H., & Costill, D. L. (1994). *Physiology of Sport and Exercise.* Champaign, IL: Human Kinetics.

11.0 APPENDIX A - PWC AND FC SCORE SHEETS

Provided in this appendix are examples of score sheets that can facilitate data collection and entering the data into the computer. You are encouraged to use these examples to customize score sheets to fit the test procedures used at your facility.

Physical Work Capacity Score Sheet

Testing Organization:	
GENERAL APPLICANT DATA	
Applicant ID	Gender: Male Female
First Name	Age In Years:
Last Name	Height (In)
Address	Weight (lbs)
City	Waiver Signed? Yes No
State & Zip	Technician
Test Date m/d/y	Test Location
Company Name:	
Remarks:	
STRENGTH TESTS	
Grip: R1____/ R1____/ R2____/ L1____/ L1____/	Arm Lift: Trial 1____/ Trial 2____/
Shoulder Lift: Trial 1____/ Trial 2____/	Torso Pull: Trial 1____/ Trial 2____/
Leg Lift: Trial 1____/ Trial 2____/	
REMARKS	

Functional Capacity Score Sheet

Testing Organization:	
GENERAL APPLICANT DATA	
Applicant ID	Gender: Male Female
First Name	Age In Years:
Last Name	Height (In)
Address	Weight (lbs)
City	Waiver Signed? Yes No
State & Zip	Technician
Test Date m/d/y	Test Location
Company Name:	
STRENGTH TESTS	
Grip: R1____/ R1____/ R2____/ L1____/ L1____/	Arm Lift: Trial 1____/ Trial 2____/
Shoulder Lift: Trial 1____/ Trial 2____/	Torso Pull: Trial 1____/ Trial 2____/
Leg Lift: Trial 1____/ Trial 2____/	
AEROBIC FITNESS	
Non-Exercise Test: Self-Report Exercise Rating	
Treadmill Test: Bruce or Balke	Treadmill Time: Minutes / Seconds /
BODY COMPOSITION	
SKINFOLDS - MEN (MM)	SKINFOLDS - WOMEN (MM)
Chest	Triceps
Abdominal	Suprailium
Thigh	Thigh
FLEXIBILITY	
Sit-and-Reach Test: Trial 1 / Trial 2 /	
Remarks:	

12.0 APPENDIX B - VALIDITY OF TORSO PULL TEST

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STUDY OBJECTIVES

The torso lift isometric strength test is recommended by the National Institute of Occupational Safety and Health (NIOSH, 1977) to screen applicants for physically demanding jobs. The torso lift test is administered in a standing position with the legs straight or slightly bent. The lift bar is 17 inches from the floor. The experimental torso pull test rotates the test position 90° placing the subject in a sitting position. The pull bar is 17 inches from the platform. For the torso lift test, the subject lifts while with the torso pull test, the subject pulls back. With the exception of being rotated 90°, the subject is in the same general position, suggesting the two tests utilize the same muscle groups to generate force.

The change in position does alter the affect of gravity on test performance. For the torso lift, the weight of the upper body must be lifted, whereas the torso pull test allows the subject to lean back and utilize their upper body weight to generate force. While this changes the amount of force one can generate, it also reduces low back compression force, which reduces the risk of back injury.[1]

While the difference in test position will likely produce significantly higher Torso Pull scores, it is hypothesized that the torso lift and pull tests will be highly correlated and equally valid for estimating work capacity. Two studies were completed to examine this. The research objectives of the two studies were:

1. Study I - Determine the statistical relationship between the Torso Lift and Torso Pull tests.
2. Study II - Compare the validity of the torso lift and pull tests for estimating one’s capacity to perform common industrial work tasks.

METHODS

Methods - Study I

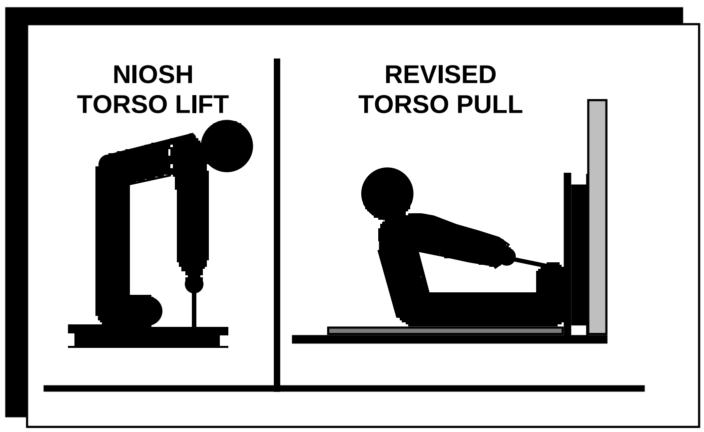
The subjects for study I included University of Houston students and job applicants for physically demanding jobs at the Brown and Root Corporation. Each subject was administered the torso pull and lift tests on the same day. The same general test procedures (one warm-up trial, two trials for score, and 3-second test duration) were followed for the each test. All tests were administered with the Jackson Evaluation System manufactured by Lafayette Equipment Company.

1. Tso-Wei Chang and Lujun Liu, graduate students in Industrial Engineering at the University of Houston, biomechanically analyzed the two tests and concluded that the sitting position produced lower low back compression forces.

Figure 17 shows the test position for the two torso tests. Standard procedures (NIOSH, 1977) were followed the torso lift test. Below are test procedures followed for the torso pull test:

- The platform was resting on end with the base against a wall.
- In this position, the distance of the cable from the bottom of the pull handle to the floor was 17 inches.
- The distance between the floor and the location of the cable on the platform was 6 inches.
- The subject sat on a mat 0.75 inches thick.
- In the test position, the subject sat with his/her legs straight and their feet firmly placed against the platform.
- The subject exerted force by pulling back and used their feet to maintain the platform against the wall.

FIGURE 17. Test positions for the NIOSH torso lift and torso pull tests.



The tests were first administered to the University of Houston students. The course instructors were trained to administer both tests by Dr. Jackson. The University of Houston sample consisted of 114 women and 89 men. The torso pull test was administered at the Brown and Root Medical facility in Houston, Texas. Dr. Jackson spent two days administering the test to Brown and Root applicants. The tests were administered at the conclusion of the required preemployment strength battery. A total of 246 applicants were tested. Of this total, only six were women.

Dr. Jackson completed all statistical analyses. Test reliability and standard errors of measurement were estimated with intraclass reliability (Baumgartner & Jackson, 1999). Regression models (Jackson, 1989; Kirlinger & Pedhazur, 1973) were used to quantify the relationship between the two tests.

Methods - Study II

The data for study II came from research completed to examine the role of strength on patient lift tasks performed by hospital workers (Jackson, Borg, Zhang, Laughery, & Chen, 1997; Jackson, Osburn, Laughery, Young, & Zhang, 1994). Ergonomic research has shown that patient lift tasks are a major cause of back injuries of hospital workers (Garg & Owen, 1992; Owen & Garg, 1991; Owen & Garg, 1993). The subjects for the second study included 91 college students (33 males and 58 females) who were paid to participate in a study. The subjects were administered both isometric strength and work sample tests that measured their static and dynamic lift capacity. The isometric strength tests measured arm, shoulder, leg, and torso strength. These tests are fully described in another source (Baumgartner & Jackson, 1999). The NIOSO torso lift (NIOSH, 1977) and torso pull tests were used to measure torso strength.

A test apparatus was developed to measure static lift capacity; The apparatus placed the test subject in the position assumed by hospital workers when required to lift a patient from a sitting to a standing position. Two static lift positions were used. The first was the front lift test position. For this common patient lift, the lifter faces the patient, bends over, and grabs the patient by a lift-belt that is around the waist, and then applies lift force. The second is the side position. It is used when two lifters lift a patient from the sitting to standing position. The lifter stands by the patient's side, reaches down, grabs the patient's lift belt, and applies lift force. For both the front and side lifts, static lift force was measured with the load cell and electronic recording unit used to measure isometric strength.

The dynamic tests involved lifting seven boxes that ranged in weight from 15 to 90 pounds. The task required the subject to lift the box from a position of about knee height and place it on a table. The vertical distance of the lift task was the distance a patient was lifted from a sitting to standing position. After completing each lift, the lifter psychophysically rated lift difficulty with Borg's CR10 scale (Borg, 1998). The test score for the dynamic lift tests was the subject's CR10 rating of lift difficulty. The validity equivalence of the two torso tests was examined with product-moment correlation. The interested reader is directed to another source (Jackson et al., 1997) for a more detailed description of this study.

RESULTS

Results - Study I

Table 26 gives the demographic characteristics of the Brown and Root sample and University of Houston students. The male and female students were the same average age. The Brown & Root applicants were about 11 years older than the students. As expected, the male students were heavier than the female students. The Brown and Root Applicants were about eight pounds heavier than the male students.

TABLE 26. Physical characteristics of the subjects.

SAMPLE	AGE (YEARS)			BODY WEIGHT (POUNDS)		
	N	MEAN	SD	N	MEAN	SD
Brown and Root	243	33.9	10.5	246	183.0	33.9
U of H Males	89	22.5	6.5	90	175.3	39.0
U of H Females	114	22.5	6.7	111	132.2	26.3

Table 27 provides the reliability analysis of the two tests. The analyses was completed on the total sample and by applicant and student samples. All reliability estimates were high, ranging from 0.91 to 0.99. The two torso tests exhibited similar accuracy across the two samples. The largest difference in the reliability coefficients between the two torso tests was only 0.01. The standard error of measurement estimates were similar.

The difference between the lowest and highest was only 2.8 pounds. For both tests, the means for the second trial was higher than the first, but the difference tended to be small (≤ 3.5 pounds) and not physiologically significant.

TABLE 27. Reliability analysis of the NIOSH torso pull and the torso lift tests.

SAMPLE	TORSO TEST	TRIAL 1	TRIAL 2	R	SEM
Total	Lift	190.4 ± 72.2	192.1 ± 73.0	0.98	13.8
Brown & Root	Lift	232.5 ± 36.9	235.1 ± 37.0	0.92	14.4
U of H	Lift	139.6 ± 71.6	140.2 ± 71.9	0.98	13.1
U of H Males	Lift	194.1 ± 66.4	194.1 ± 66.2	0.98	9.3
U of H Females	Lift	96.5 ± 38.7	96.9 ± 39.6	0.98	5.5
Total	Pull	214.3 ± 67.7	216.3 ± 67.4	0.98	12.8
Brown & Root	Pull	245.6 ± 34.2	249.1 ± 33.7	0.91	13.7
U of H	Pull	176.4 ± 78.0	176.7 ± 76.1	0.99	11.6
U of H Males	Pull	239.7 ± 62.6	240.8 ± 58.8	0.99	6.0
U of H Females	Pull	126.5 ± 46.3	126.2 ± 43.0	0.99	5.0

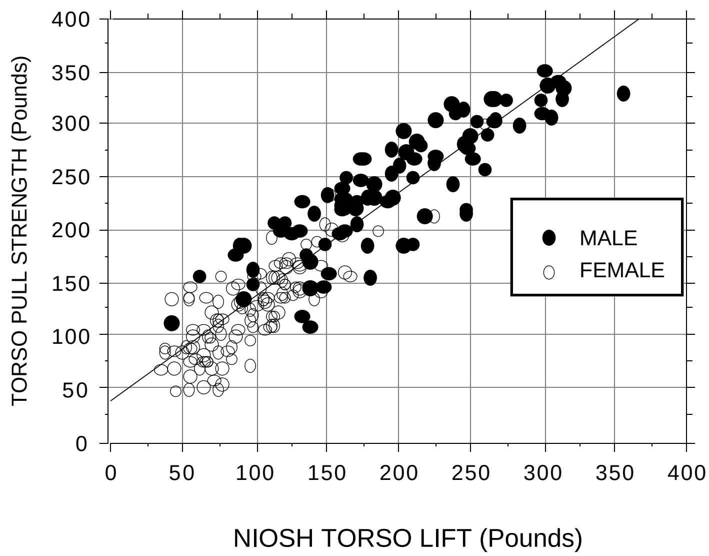
Table 28 gives the means and standard deviations for the two torso tests for the male and female students and Brown & Root applicants. As hypothesized, the means for the Torso Pull test were higher than the Torso Lift test. The means of the college students exhibited the typical gender difference. The average Torso Lift of the females was 49.7% of the males' average. The gender difference for the Torso Pull was slightly smaller. The percentage of female to male strength was 52.6%. These gender differences are consistent with published data (NIOSH, 1977). The means of the Brown and Root applicants were higher than the male students.

TABLE 28. Comparison of descriptive statistics for the two torso tests.

SAMPLE	TORSO LIFT			TORSO PULL		
	N	MEAN	SD	N	MEAN	SD
Total	450	191.3	71.9	450	215.3	66.9
Brown and Root	246	233.8	35.5	246	247.3	32.5
U of H	204	139.9	71.2	204	176.6	76.6
U of H Males	90	194.5	65.3	90	240.2	60.0
U of H Females	114	96.7	38.5	114	126.3	44.0

Figure 18 shows the bivariate relationship between the torso lift and pull tests. The torso lift and pull tests were highly correlated, r = 0.91. Figure 18 gives the regression line for the male and female subjects. The slope of the regression line was 0.988, which is within chance variation of 1.0 ($t_{(df=202)} = 0.40$; $p > 0.05$). The intercept of the regression line was 38.422, which is significantly larger than 0 ($t_{(df=202)} = 8.11$; $p < 0.0001$). This shows that, for the same level of torso strength, the torso pull scores are about 38 pounds higher than the torso lift scores.

FIGURE 18. Bivariate relationship between the Torso Pull and Torso Lift tests. The slope of the regression line (black line, slope = 0.973) is not significantly different from the line of identity (slope = 1).



Results - Study II

The purpose of study II was to determine if the torso lift test was as valid for estimating work capacity as the NIOSH torso lift test. Table 29 is the correlation matrix of the arm, shoulder, leg, and torso isometric strength tests. The product-moment correlation between the two torso tests is 0.90, nearly identical to the correlation of 0.91 found in study I. The correlations between the two torso tests and the other three strength tests are similar. The largest difference is for the arm lift test. The correlation between arm lift and torso pull is 0.89, slightly higher than the 0.83 correlation for arm lift and the NIOSH torso lift tests.

TABLE 29. Intercorrelations among arm, shoulder, leg, and torso isometric strength tests.

TEST	1	2	3	4	5
1. Arm Lift	1.00				
2. Shoulder Lift	.93	1.00			
3. Leg Lift	.87	.88	1.00		
4. NIOSH Torso Lift	.83	.81	.89	1.00	
5. Torso Pull	.89	.83	.87	.90	1.00

Table 30 gives the product-moment correlations between the two torso strength tests and the work sample lift tests. The leg, arm, and shoulder strength tests are provided for comparison. All correlations in Table 30 are statistically significant. The correlations between the lift and two torso tests are nearly identical. The largest difference is only .03 correlation units and for both tests (CR10 75 pounds and isometric side lift), the correlations for the torso pull test were higher than the NIOSH torso lift test. The data given in Table 30 demonstrate that the validity of the torso lift test equals that of the NIOSH torso lift test.

TABLE 30. Product-moment correlations between isometric strength tests and work sample lift tests.

TEST	TORSO TESTS		OTHER ISOMETRIC TESTS		
	PULL	LIFT	LEG	ARM	SHOULDER
CR10 - 15 Pounds	-.27	-.26	-.23	-.30	-.33
CR10 - 30 Pounds	-.49	-.49	-.48	-.52	-.55
CR10 - 45 Pounds	-.53	-.53	-.48	-.54	-.57
CR10 - 60 Pounds	-.53	-.51	-.50	-.55	-.57
CR10 - 75 Pounds	-.63	-.60	-.61	-.69	-.69
CR10 - 85 Pounds	-.66	-.65	-.65	-.73	-.70
CR10 - 90 Pounds	-.69	-.69	-.69	-.79	-.76
Isometric Front Lift	.70	.72	.69	.64	.61
Isometric Side Lift	.85	.82	.86	.80	.75

Summary

While the scores of the torso lift test are systematically higher than the torso pull test, the same muscle groups are used to generate force. The systematic mean difference is due to test position. The torso lift test requires that the subject lift their torso, which adds to the load the subject must lift.The high correlations between the two tests (studies I and II) demonstrate that the two torso tests are equivalent. This is logical because force is being generated by the same muscle groups. Not only are the tests highly correlated, but they are equally valid for estimating lift capacity, a very common industrial work task.

REFERENCES

Baumgartner, T. A., & Jackson, A. S. (1999). *Measurement for Evaluation in Physical Education and Exercise Science.* (6th ed.). Dubuque: Wm. C. Brown.

Borg, G. (1998). *Borg's Perceived Exertion and Pain Scaling Method*. Champaign: Human Kinetics.

Garg, A., & Owen, B. (1992). Reducing back stress to nursing personnel: an ergonomic intervention in a nursing home. *Ergonomics*, 35(11), 1353-1375.

Jackson, A. S. (Ed.). (1989). Chapter 9: Application of regression analysis to exercise science. M.J. Safrit and T.M. Wood (eds) *Measurement Concepts in Physical Education and Exercise Science.* Champaign: Human Kinetics.

Jackson, A. S., Borg, G., Zhang, J. J., Laughery, K. R., & Chen, J. (1997). Role of physical work capacity and load weight on psychophysical lift ratings. *International Journal of Industrial Ergonomics*, 20, 181-190.

Jackson, A. S., Osburn, H. G., Laughery, K. R., Young, S. L., & Zhang, J. J. (1994). Patient Lifting Tasks at Methodist Hospital. Houston: Center of Applied Psychological Services, Rice University.

Kirlinger, F. N., & Pedhazur, E. J. (1973). *Multiple Regression in Behavioral Research.* New York: Holt, Rinehart and Winston, Inc.

NIOSH (1977). *Preemployment Strength Testing*. Washington: U.S. Department of Health and Human Services.

Owen, B. D., & Garg, A. (1991). Reducing risk of back pain in nursing personnel. *AAOHNJ*, 39, 24-33.

Owen, B. D., & Garg, A. (1993 (February)). Back stress isn't part of the job. A*merican Journal of Nursing,* 48-51.

Ross, R. M., & Jackson, A. S. (1990). *Exercise Concepts, Calculations, and Computer Applications*. Carmel, IN: Benchmark Press.

13.0 APPENDIX C - EXAMPLE OF TASK ANALYSIS QUESTIONNAIRE

Provided in this appendix is an example of a task analysis questionnaire. The questionnaire illustrates a frequency and effort scale that can be used to rate work tasks. Provided in the second section are examples of task statements from each of the three work families. These are provided as examples. To develop a task questionnaire it would be necessary to replace the sample task statements with statements that represent the work tasks of the specific job.

Frequency and Effort Rating Scales

INSTRUCTIONS: This questionnaire contains a list of tasks that are performed by (company name) employees. The purpose of this questionnaire is to identify your physically demanding work tasks. This information will be used to define standards for hiring new employees. The goal is to be able to hire workers who are physically able to do the work. Do not put your name on the questionnaire, but please provide the following information:

Rate HOW OFTEN (Frequency) you perform each of the tasks listed on this questionnaire. Use the following scale for making your ratings on frequency.							
FREQUENCY SCALE							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Do not perform the task	Once a year or less	2-6 times a year	About once a month	About once a week	Several times a week	About once a day	Several times a day or more

Please use the scale below for making your rating on the EFFORT or, how physically demanding the task is.							
EFFORT SCALE							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Nothing at All	Very, Very Easy	Very Easy	Easy	Somewhat Hard	Hard	Very Hard	Very, Very Hard

Sample Task Statements

Materials Lifting Tasks

Task Statement	Ratings	
	Freq.	Effort
1. Lifting/lowering 50- to 75-pound loads from/to floor and waist height.		
2. Lifting/lowering 75- to 100-pound loads from/to floor and waist height.		
3. Lifting/lowering loads greater than 100 pounds from/to floor and waist height.		
4. Lifting/lowering 50- to 75-pound loads from/to waist and above shoulder height.		
5. Lifting/lowering 75- to 100-pound loads from/to waist and above shoulder height.		
6. Lifting/lowering loads of greater than 100 pounds from/to waist and above shoulder height.		
7. Continuously lifting/lowering 30- to 40-pound boxes (10 or more).		
8. Continuously lifting/lowering 40- to 50-pound boxes (10 or more).		
9. Lifting/lowering oversized freight (e.g., furniture boxes, pipe tubing) that is awkward to handle and weighs less than 50 pounds.		
10. Lifting/lowering oversized objects (e.g., furniture boxes, pipe tubing) that is awkward to handle and weigh between 50 and 75 pounds.		

Maximum Force Tasks

Task Statement	Ratings	
	Freq.	Effort
1. Moving freight with a two-wheel dolly.		
2. Moving freight with a 4-wheel flat.		
3. Moving freight with a pallet jack.		
4. Transporting 55-gallon drums with a dolly.		
5. Moving 55-gallon drums by hand.		
6. Lifting dock plate and putting it in place on the trailer.		
7. Breaking rusted bolts 1 1/4” to 1 5/8” bolts.		

Task Statement	Ratings	
	Freq.	Effort
8. Breaking/opening/closing valves in awkward (kneeling, overhead or bent) positions.		
9. Breaking/opening/closing 4" to 6" valves in corrosive/dirty, and/or high pressure service (over 1000 psi).		

Endurance Work

Task Statement	Ratings	
	Freq.	Effort
1. Climbing up/down stairs carrying tool bags offshore.		
2. Climbing up/down stairs while pulling hose extinguisher in one hand and keeping other hand free for holding onto handrail		
3. Climbing up/down stairs carrying extinguisher in one hand and keeping the other hand free for holding onto rail.		
4. Opening/closing 4" to 6" valves in high pressure service (over 1000 psi).		
5. Rapidly unloading container full of freight.		
6. Loading the belly compartment of the air craft with document bags while in a crouched position.		
7. Shoveling coal from the floor onto the conveyor belt.		
8. Repeatedly lifting 50-pound bags of material and transporting them 10 feet and placing them on a dolly.		