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Testing Individual Capability to Lift Material: Repeatability of a Dynamic Test Compared with Static Testing

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This paper describes a new dynamic testing procedure of individual lift capability and its laboratory evaluation with 39 subjects. In test-retesting, the isoinertial "LIFTEST" proved to be less variable than standard isometric lift tests.

Overexertion injuries, many of the lower back, constitute at least one fourth of all compensable injuries in U.S. industry. Therefore, procedures to avoid or at least to reduce such incidents are of critical importance. About 4.6 billion dollars are paid annually by U.S. worker compensation insurance companies for low back injuries. The cost to industry is much higher (National Institutes for Occupational Safety and Health [NIOSH], 1981).

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The basic means to avoid such injuries is to design the job so that workers need not lift, lower, push, pull, carry, hold, etc. excessively. Ergonomic design of the job is the primary and most efficient way to avoid overexertion injuries. Secondary means should also be applied, however, such as selection (and training) of workers so that they are able to perform physically demanding tasks. Screening of persons to be transferred to or newly hired for jobs that require manual material movement is of great interest to industry, insurance companies, and society at large (Kroemer, 1979; Snook, Campanelli, & Hart, 1978).

Medical screening of individuals for their ability to perform manual material movement has been effective mostly in discovering gross inadequacies of the musculo-skeletal, pulmonary, or circulatory systems. Epidemiological, biomechanical, physiological, and psychophysical techniques have been applied to assess job demands and related capabilities or limitations of the worker. A combination of these approaches led to the 1981 NIOSH *Work Practices Guide for Manual Lifting.*

This publication, however, relies largely on static biomechanic considerations, which have limited application to dynamic lifting situations (Ayoub, 1982; Rodgers, 1982).

Most lifting in industry is performed dynamically. Hence, there is much appeal in the idea of using a dynamic technique to test a person's lifting capability, as opposed to static strength testing. However, no simple, reliable, standardized technique has been available. Recognizing the need, NIOSH sponsored research to develop a dynamic testing technique. The following text describes that research. (See also Kroemer, 1982, and Kroemer, 1983.)

DEVELOPMENT OF LIFTEST

Among dynamic testing techniques, two are of particular interest:

1. *Isokinetic technique*, in which the speed of the body segments involved is preselected and constant during the test. The strength (torque) which the subject can develop during the motion is measured.
2. *Isoinertial technique*, in which a preselected mass, constant during each test section, is lifted. By increasing the mass in each subsequent effort, the maximum mass (weight) acceptable to the subject is determined.

In the isokinetic technique, the experimenter controls the speed of operation. Equipment is on the market that allows the continuous measurement of muscular strength while the subject is in motion. Such equipment and associated lifting capability tests have been recently described and found to be superior to isometric strength testing for predicting actual lifting capacity on the job (Kamon, Kiser, & Pytel, 1982). A major disadvantage of the isokinetic technique is that the movement speed must be preselected and must remain constant during the motion.

In the isoinertial technique (familiar to many from competitive sports, gymnasiums, and health clubs), the task is similar to actual material lifting in that, within limitations imposed by the test protocol, the subject is free to use any subjectively suitable lifting technique. According to Newton's Law, the actually exerted force (strength) depends on the acceleration applied to the constant mass. While apparently more "realistic" than the isokinetic technique, the isoinertial lift measurement has binary nature (success or failure) compared to the quantitative isokinetic measurement.

To assess the feasibility of the isoinertial technique, a "press station" called Mach I[1] was selected on the basis of availability, price, and ease of modification. In its original configuration, it included two upright carriage guide channels 80 in. (2 m) long, spaced 13 in. (33 cm) apart, made of 3/8-in. (9-mm) rolled steel. In cross section, they are C shaped, enclosing self-aligning plastic wheels. The wheels guide a cast iron carriage which is moved via a horizontal handle on its front. On its rear side, a pin-and-channel design allows attaching various masses (flat iron weights).

For the experiments, the guide rails were extended to 120 in. (3 m) to accommodate the full overhead reach capability of tall persons from the floor. A new carriage was made of aluminum, reducing its weight including the handles to 15 lb (6.8 kg). For comparison with isometric testing equipment (Chaffin, 1975; Chaffin, Herrin, & Keyserling, 1978), the handle assembly was changed to have two handles, 18 in. (46 cm) apart, horizontal and parallel to each other, pointing forward. A lightweight "shield" was placed in front of the stack of weights, and a second shield attached to the carriage, so that the subjects would not see how much they were lifting. Figure 1 depicts the new dynamic lift-strength-testing device, called LIFTEST for convenience.[2]

TESTING OF LIFTEST

In order to establish the test-retest reliability (repeatability) of the LIFTEST procedure and equipment, experiments were performed

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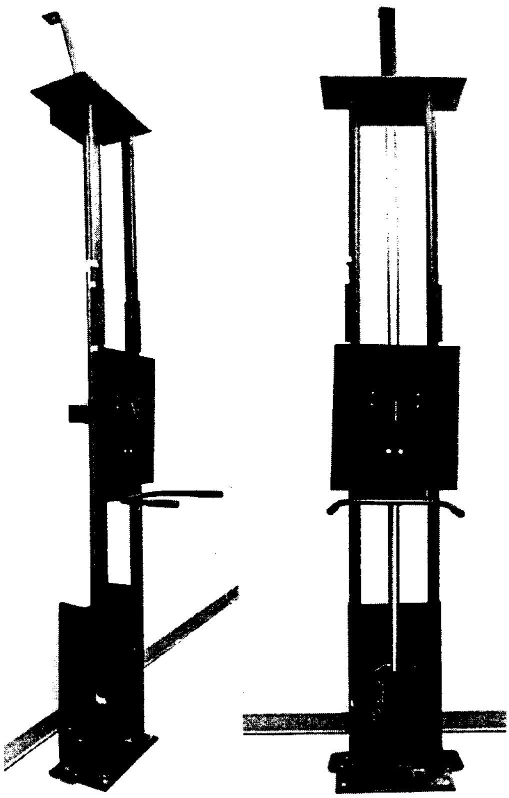
[1]Manufactured by Marcy Gymnasium Equipment Co., 2801 W. Mission Road, Alhambra, CA 91803.

[2]Since LIFTEST equipment is simple in design and easily dismantled, it can be quickly transported in a stationwagon or small truck to different experimental sites or, perhaps more conveniently, be installed in a mobile laboratory vehicle. Furthermore, it is relatively inexpensive and might therefore be acquired with ease and installed permanently in the examination room, e.g., of a plant physician.

FIGURE 1
FRONT AND SIDE VIEW OF
THE EXPERIMENTAL LIFTEST EQUIPMENT



in the Ergonomics Laboratory of Virginia Polytechnic Institute and State University. Since the test results were to be compared with those obtained in conventional static lift-strength-testing procedures, subjects employed in the assessment of LIFTEST were also tested for their static force capabilities.

Experimental Hypothesis

The primary experimental hypothesis in this research was: The test-retest reliability (repeatability) of the results obtained with the LIFTEST equipment, for both overhead reach height and knuckle height, is similar to, or better than, the reliabilities reported for static strength tests.

Accordingly, the primary dependent variables in these tests were (a) the amounts of weight that the subjects would lift voluntarily using the LIFTEST equipment, and (b) the subjects' maximum voluntary isometric strengths exerted on static measurement devices. Independent variables were the individual capabilities of the subjects and the testing techniques.

Experimental Design

An experimental procedure was developed to: (a) measure individual maximum LIFTEST capabilities for both overhead reach and knuckle height; (b) assess isometric arm, leg, torso, and shoulder strengths; (c) determine the maximum weight that subjects would be willing to lift once per minute over an 8-hour shift; and (d) measure their dynamic endurance.[3] LIFTEST experiments and the static strength measurements were performed three times in order to establish test-retest reliability. Demographic information and anthropometric measurements were also obtained from the subjects.

With each subject, the experimental procedure was as follows:

1. Introduce the study and explain its general purpose and procedures.
2. Read, discuss, and sign consent forms.
3. Fill in questionnaire regarding physical activities.
4. Perform first series of static strength measurements and of LIFTESTs in random order.
5. Obtain demographic information.
6. Perform second series of tests in random order.
7. Measure anthropometric dimensions.
8. Run third series of tests in random order.
9. Determine repeated voluntary maximum lift (once per minute for 8 hours).
10. Measure dynamic endurance.

The experimental session with each subject lasted about 2 hours. Rest periods of at least 2 minutes were interspersed between all tests that required dynamic or static strength exertions. The subject was cautioned not to hurt himself/herself while cooperating fully. No information about the scores achieved was given during the experimental sessions.

[3]This paper discusses only the LIFTEST and static strength measurements. Full details are given in a report to NIOSH (Kroemer, 1982).

Test Procedure

LIFTEST was performed as follows: The subject grasped both handles, located about 2 in. (5 cm) above the floor, and lifted them as rapidly and comfortably as possible to knuckle height or to overhead reach height, then guided the handles down. Each subject started with an initial weight of 25 lb (11.4 kg) to become familiar with test equipment and procedure. The next test was with double this weight. If this weight was lifted, 75 lb (34 kg) were attempted. If this was successful, another 25-lb (11.4 kg) increment weight was added until the cut-off limits (see below) were reached. If an attempt failed, the weight was reduced by 15 lb (6.8 kg). If this test weight was lifted, 10 lb (4.5 kg) were added; if not, 5 lb (2.3 kg) were subtracted. This scheme of adding 25 lb (11.4 kg), subtracting 15 lb (6.8 kg), adding 10 lb (4.5 kg), or subtracting 5 lb (2.3 kg) quickly determined the weight that a subject could lift.

For LIFTEST repetitions, the subject began with 10 lb (4.5 kg) less than previously lifted. Depending on the subject's success or failure with this initial weight, 5 lb (2.3 kg) increments were added or subtracted until the maximum load (see below) was determined.

The isometric strength tests were administered as prescribed by Chaffin et al. (1978).

Equipment

In addition to questionnaires and standard anthropometric tools, the following equipment was used:

The LIFTEST equipment described earlier was used to determine the maximum weights each subject could lift. The minimum weight was 25 lb (11.4 kg), increments were in 5 lb (2.3 kg). The maximum loads were 170 lb (77.3 kg) in knuckle height tests and 100 lb (45.5 kg) in overhead reach height tests. These cut-offs were selected to avoid overexertion risks, as recommended by other researchers (Chaffin, 1981; Keyserling, Herrin, Chaffin, Armstrong, & Foss, 1980; McDaniel, Skandis, & Madole, 1983).

An "Employee Strength Measurement Force Monitor" (University of Michigan) was used for the static strength measurements. Essentially, this equipment consists of a load cell, anchored to the floor and connected by ropes or chains to vertical handle assemblies. The handles are two wooden cylinders, 4 in. (10 cm) long and 1 in. (2.5 cm) in diameter, running parallel to each other 6 or 18 in. (15 or 45 cm) apart. The force applied to the handles is averaged over a 3-second period and displayed in lb or kg.

All experiments were performed in the Ergonomics Laboratory of Virginia Polytechnic Institute and State University. This is a windowless laboratory of approximately 750 sq ft (70 m^2), centrally air conditioned, isolated from outside activities. During the tests one or two experimenters were present together with one subject.

Subjects

Subjects were recruited through advertising on the campus of Virginia Polytechnic Institute and State University and were paid by the hour. No special selection procedures were applied, but no one applied or participated who was unable to perform the physical tasks involved. During the introductory part of the experimental session, subjects were questioned about physical disabilities, previous injuries, and other traits that would have made it inadvisable to participate in the experiments. No subjects opted, or were advised, not to participate. Table 1 summarizes the characteristics of the 39 subjects who participated.

RESULTS

Table 2 summarizes the main results obtained in this study. In the LIFTESTs to overhead reach height, 6 of the 25 males exceeded the cut-off load of 100 lb (45.5 kg), while all 14 females stayed below this limit. The remaining 33 subjects lifted, on the average, 59 lb (27 kg); males averaged 76 lb (35 kg) and females 36 lb (16 kg). The average coefficients of variation are 3.2% for males, and 3.9% for females.

In the LIFTESTs to knuckle height, the maximum load of 170 lb (77.3 kg) was exceeded by 17 male subjects. The remaining 22 subjects lifted, on the average, about 118 lb (54 kg); males averaged 137 lb (62 kg) and females 108 lb (49 kg). The average coefficients of variation are 5.2% for males, and 7.8% for females.

TABLE 1
CHARACTERISTICS OF SUBJECTS
PARTICIPATING IN LIFTING CAPABILITY EXPERIMENT

	ALL ($N = 39$)		MALE ($n = 25$)		FEMALE ($n = 14$)	
CHARACTERISTICS	$\bar{X}$	*SD*	$\bar{X}$	*SD*	$\bar{X}$	*SD*
Age in years	21.15	1.86	21.80	1.61	20.00	1.75
Weight in lb (kg)	146.78 (66.72)	23.19 (10.54)	157.06 (71.39)	18.17 (8.26)	128.46 (58.39)	19.91 (9.05)
Height in in. (cm)	68.08 (173.24)	3.42 (8.69)	69.73 (177.42)	2.59 (6.59)	65.16 (16.79)	2.70 (6.87)

In the static strength tests, the average isometric arm force was 54 lb (25 kg), the average isometric leg force was 143 lb (65 kg), and the average isometric torso force was 132 lb (60 kg). In each of these tests, the female subjects were, on the average, about 50% weaker than the male subjects. The coefficients of variation range from 11.6 to 15.4%.

DISCUSSION

Test-retest reliability (repeatability) was the major topic of the experiments. The coefficient of variation (standard deviation divided by mean) is a measure of the average intra-individual variability in test repetitions. The results of these calculations, shown in Table 2, indicate a very consistent performance by each subject within his or her three LIFTEST exertions, i.e., 3.2% for the male and 3.9% for the female subjects in the Overhead LIFTESTs. Similar low coefficients of variation were also found in related ("X-Factor") tests performed by the U.S. Air Force (McDaniel et al., 1983) and in psychophysical tests of manual material handling (Snook, 1978).

In comparison, in the static force tests, the same subjects showed considerably higher variability, ranging from 12.7 to 14.3% for the males and from 11.6 to 15.4% for the females. These results are within ranges found in industry (Chaffin et al., 1978) and within the range of 5 to 15% reported by various researchers (Chaffin, 1975; Keyserling et al., 1980; Chaffin, 1981).

Since all tests were run under the same conditions, the coefficients of variation indicate a much more consistent performance in the dynamic LIFTESTs than in the standardized static force tests. This is a remarkable result, particularly when considering that the individual strength capabilities of the subjects were quite varied, as the means and standard deviations in Table 2 indicate.

Even the knuckle height LIFTESTs show a relatively low variation compared to static tests. The LIFTESTS to knuckle height are more variable than the tests to overhead reach, however, and obviously require manipulation of heavier weights. Thus, overhead LIFTESTs appear preferable to knuckle height tests.

Using the data obtained in this research, multiple regression equations were calculated in an attempt to predict LIFTEST performance from static strength measurement (Kroemer, 1982). While simple correlation coefficients between a given static strength measurement and LIFTEST performance reached values as high as .7, their combined predictive power R^2 stayed below .60 in all possible combinations. Such relatively low relationships between static and dynamic performance measures were also reported in studies of isokinetic (Kamon et al., 1982) and isoinertial lifting (McDaniel et al., 1983).

CONCLUSIONS AND OUTLOOK

The results indicate test-retest reliabilities (repeatabilities) of dynamic Overhead LIFTEST data that are considerably better than the reliabilities reported for static muscle strength tests. A comparable isoinertial test ("X-Factor Test") has been applied since 1976 to all male and female Air Force recruits for their job placement (McDaniel et al., 1983), with considerable reduction in over-

TABLE 2
LIFTEST AND STATIC FORCE MEASUREMENTS

TEST	ALL SUBJECTS $\bar{X}$	ALL SUBJECTS SD	ALL SUBJECTS CV	ALL SUBJECTS N	MALE SUBJECTS $\bar{X}$	MALE SUBJECTS SD	MALE SUBJECTS CV	MALE SUBJECTS n	FEMALE SUBJECTS $\bar{X}$	FEMALE SUBJECTS SD	FEMALE SUBJECTS CV	FEMALE SUBJECTS n
Overhead LIFTEST in lb (kg)	59.29 (26.95)	22.71 (10.32)	3.5%	33	76.49 (34.77)	11.49 (5.22)	3.2%	19	35.95 (16.34)	8.24 (3.75)	3.9%	14
Knuckle LIFTEST in lb (kg)	118.49 (53.86)	29.37 (13.35)	6.9%	22	136.88 (62.22)	17.24 (7.84)	5.2%	8	107.98 (49.08)	30.11 (13.69)	7.8%	14
Static arm force in lb (kg)	54.13 (24.61)	22.56 (10.25)	13.2%	39	65.40 (29.73)	19.25 (8.75)	14.0%	25	34.02 (15.46)	11.20 (5.09)	11.6%	14
Static leg force in lb (kg)	143.02 (65.01)	67.12 (30.51)	13.7%	39	173.03 (78.65)	62.15 (28.25)	14.3%	25	89.41 (40.64)	34.79 (15.81)	12.5%	14
Static torso force in lb (kg)	132.15 (60.07)	169.91 (77.23)	13.7%	39	158.74 (72.15)	56.76 (25.80)	12.7%	25	84.67 (38.49)	27.50 (12.50)	15.4%	14

exertion injuries claimed. Accordingly, the U.S. Army is now applying a similar test to its soldiers. This encourages the validation of an inertial procedure like LIFTEST in industry, so that it may be used in pre-employment or preplacement tests of the individual lift capability in order to help reduce the risk, frequency, and severity of overexertion injuries, particularly of the low back (Rothstein, 1984; Rowe, 1983).

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