Progressive Isoinertial Lifting Evaluation
I. A Standardized Protocol and Normative Database

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Dynamic tests of trunk strength and lifting capacity have become more popular in recent years, offering certain advantages over static isometric tests in measuring patient progress in functional restoration programs for spinal disorders. However, equipment for performing such tests is expensive to buy, complex to run, and requires technical expertise and clinical volume unavailable in most physician offices. In this study, a new dynamic test known as Progressive Isoinertial Lifting Evaluation (PILE) is described, which draws upon prior psychophysical and isoinertial methods. An industrial sample of 61 male and 31 female incumbent workers were tested using the PILE, and a variety of anthropometric normalizing factors were evaluated. The isolation of an "Adjusted Weight" (AW) normalizing factor is documented, after which normative data are presented for male and female workers utilizing lumbar (0–30 inches) and cervical (30–54 inches) dynamic protocols. [Key words: physical capacity assessment, quantitative functional evaluation, isoinertial, isokinetic, psychophysical lifting tests, functional restoration, low-back pain (LBP), spinal disorders, chronic low-back pain (CLBP), neck pain, cervical dysfunction]

QUANTIFICATION OF PHYSICAL FUNCTION to document the "Deconditioning Syndrome" is receiving increasing attention among scientists and clinicians who deal with chronically disabled back-injured workers complaining of low-back pain (LBP). Quantification is being used in rehabilitation to support the rapidly proliferating reconditioning, work-hardening, and functional restoration programs.[24-27] Its usefulness also has been suggested, though still unproven, for worker selection and disability evaluation.[3,4,8,17,21,27,35,44] Worldwide, the literature of functional evaluation is rapidly increasing as new technology becomes available, but as yet there is no standardization of methodology.[9,11,14,20,23,27,29,42,43]

The quantification of lifting capacity is an especially important area of such functional evaluation. Indeed, lifting incidents have been associated with a significant percentage, varying from 15 to 65%, of work-related low-back pain episodes.[1,2,12,13,15,38] Injury rates up to eight times higher have been described for workers subjected to regular heavy lifting. This is felt by some investigators to be related to elevated disc pressures compared with those lifting light loads.[20,29,45] Much ergonomic literature has arisen around job redesign to lower risk of inadvertent injury through lifting strains.[6,7,17]

While workplace modification through job analysis has been the primary focus of this work, much interest has been devoted to "strength testing," involving isometric lifting in industry.[5-8,16,17,22,30-32,36,37] Isometric strength testing has been recognized in the NIOSH (National Institute for Occupational Safety and Health) Work Practices Guide for Manual Lifting as a reasonable way to identify workers who would be at highest risk of overexertion injury, and this has led to early clinical use of lifting tests for worker selection, and even disability evaluation purposes. The history of worker selection, however, is fraught with controversy and prior discrimination.[26,33,34] The validity and safety of static testing has been questioned, and the doubtful predictive value of pre-employment screening continues to raise doubts about clinical and industrial utility. Recent work by Troup and colleagues suggests a low predictive value of the battery of psychophysical/isometric tests for future LBP.[44]

Currently, several lifting tests, both static and dynamic, are available to the investigator. Static tests,[5-7,30,31] as well as isokinetic dynamic tests[18] and psychophysical and isoinertial protocols, are currently being used.[19,41,44] The latter tests have never achieved clinical popularity despite low cost and easy transportability, possibly because of the subjective nature of the psychophysical lifting endpoint (namely, the point of "discomfort" or subjective perception of "overexertion"). In addition, the complete freedom inherent in unconstrained lifting (no anatomic stabilization or control of speed/acceleration variables, as are inherent in semiconstrained isokinetic or constrained isometric methods) raises questions as to the validity and reproducibility of the test. These objections often are counterbalanced by the fact that psychophysical tests represent truly self-selected "real world" lifting techniques, whose advantage may lie precisely in the fact that they do not compromise coordination and agility variables used by the trained lifter. As yet, the ideal lifting test providing valid dynamic measurements that are relevant to the physiology, and which is safe, simple, and inexpensive to perform with an appropriate effort factor has failed to emerge.

Nevertheless, the promise of a simple, portable, and easily evaluable test continues to hold appeal for scientists interested in worker rehabilitation, selection/placement, and disability evaluation. At the University of Texas Southwestern Medical Center at Dallas and the Productive Rehabilitation Institute of Dallas for Ergonomics (PRIDE), a standardized protocol for Progressive Isoinertial Lifting Evaluation (PILE) employing psychophysical and isoinertial lifting characteristics has been developed and modified over several years. It is the purpose of this study to present this technique with a normative database, and to discuss its use as part of a complete battery of physical capacity evaluation tests.

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MATERIALS AND METHODS

Overview of Technique. A sequence of incremental weight lifting, identical for individuals of like gender, was implemented in the present protocol. Because lifting capacity incorporates aerobic activity, it was important to establish a cardiovascular end-point that simultaneously functions as an "effort factor." This test end-point also establishes whether aerobic capacity or neuromuscular fatigue in either the trunk or extremities is the limiting factor of task performance.

The PILE protocol involves the lifting of weights in a plastic box in 1) a lumbar test from floor to waist (0-30 inches), and 2) a cervical test evaluating shoulder girdle and upper extremity lift capacity from waist to shoulder height (30-54 inches). Women begin with an 8-pound load (5-pound iron bar plus weight of container), while men begin with a 13-pound load (10-pound iron bar plus container weight). Weight is incremented upwards at a rate equal to the initial free weight (ie, 5 pounds for women, 10 pounds for men) every 20 seconds, with a rate of four lifting movements in each 20-second interval (Figure 1). A "lifting movement" involves a single transfer from one level to the next, ie, from floor to waist (0-30 inches), or waist to shoulder (30-54 inches). Lifting progresses in sequence, floor to waist to floor, unless the patient reaches an end-point. Lumbar and cervical PILE tests are done separately, since norms and biomechanics differ for varying lift heights. The test is terminated when the first of the following end-points is achieved:

1) *Psychophysical End-point.* Voluntary test termination by the subject for complaints of fatigue, excessive discomfort, or inability to complete four lifting movements in a 20 second interval;

2) *Aerobic End-point.* Achievement of a specific aerobic capacity goal, usually 85% of age-determined "maximum heart rate" (unless cardiac precautions are in force or rate-limiting medications are being taken); or

3) *Safety End-point.* A predetermined anthropometric "safe limit" of 55 to 60% of body weight.

Results are expressed as: 1) maximum weight lifted (for both lumbar and cervical PILE tests); 2) the endurance time to discontinuation of test; 3) the final and target heart rates; 4) total work; and 5) power consumption. Since distance and endurance time are also known, calculations of work and power consumption can be performed easily and normalized to anthropometric factors. Because Work equals Force × Distance, and the distance traveled for each 20-second portion of each protocol is known (10 ft = 3.05 m; 8 ft = 2.44 m), the total work performed is simply the sum of the forces lifted multiplied by this distance. For example, if a female subject reaches an end-point after completing 100 seconds of lumbar testing, she will have a Final Force of 28 pounds (the weight lifted in the final 20 seconds). She will have performed Total Work (TW) on lumbar PILE, which is calculated as follows:

$$TW = [8 + 13 + 18 + 23 + 28] \times 10 = 900 \text{ lb-ft} \quad (1)$$

Total Power consumption (TP) is the work performed divided by the unit of time and is represented:

$$TP = TW/t = 900 \text{ lb-ft}/100 \text{ sec} = 9 \text{ lb-ft/sec, or } 12.4 \text{ W} \quad (2)$$

Conversely, if the same subject performs the cervical test in identical fashion (but with distance travelled per 20 seconds being 8 rather than 10 ft,) then:

$$TW = [8 + 13 + 18 + 23 + 28] \times 8 = 720 \text{ lb/ft} \quad (3)$$

$$TP = 720 \text{ lb-ft}/100 \text{ sec} = 7.2 \text{ lb-ft/sec, or } 9.9 \text{ W} \quad (4)$$

When combined with the knowledge of the type of end-point reached, these levels of work performance and power consumption represent a maximum for that individual based on the three primary limiting factors of patient capability: cognitive, cardiovascular, and anthropometric (represented, respectively, by psychophysical, aerobic, and safety end-points).

Fig 1. Subject performing the PILE test, progressively incrementing weights in either the lumbar (0-30 inches) or cervical (30-54 inches) test.

In effect, the reasonable limits for subject frequent lifting in industry, as well as the limiting factor, are documented by the PILE test. To understand this point, one must fully comprehend the implications of the measurements. If a subject is stopped by reaching the aerobic end-point, then cardiovascular factors are limiting the subject's performance. This generally occurs only in older or very large individuals, whose endurance time is prolonged and whose total work therefore is increasing exponentially. An individual being stopped by the safety end-point is limited by anthropometric factors; this generally occurs only in very thin and small individuals. The vast majority of subjects are stopped by the psychophysical end-point, which is an objective measure of the patient's perception of fatigue or overexertion. Rather than self-selecting a single isometric or isoinertial lift that is "acceptable,"[40,41,44] the subject progressively increases weight lifted and total work until an objective end-point is reached. If submaximal effort is provided, final heart rate will be low, and a discrepancy between target heart rate and final heart rate will be displayed. In most individuals, this provides a guide to patient effort that can be validated against separate bicycle ergometry or treadmill tests of aerobic capacity. Thus, if a subject taking no rate-limiting cardiac medications with high levels of aerobic capacity on bicycle ergometry demonstrates deficient lifting capacity associated with a psychophysical end-point and low heart rate, the subject has demonstrated submaximal effort. The observer then may assume partial invalidation of test by limited effort, implying that the patient's true testing capability is

er than that displayed. This observation may be diagnostic by ·itting inferences regarding the need for psychosocial evaluation, education, or training to be drawn.

·en the test is placed into the context of the normative data- additional information may be provided. If a series of in- ·ents in a given industry requiring continuous moderate to y lifting are subjected to PILE testing, a normal distribution : can be developed for these workers. It may be assumed that final force, TW, and TP (normalized to some anthropometric acteristics such as height or weight) is characteristic of work- ·ho are capable of performing the strenuous job for a full ur period. A job applicant exceeding mean normalized val- f force, TW, and TP, as well as predetermined minimal final : values, without reaching an aerobic end-point, may then be ·ed as having achieved lifting, cardiovascular, and endurance ·bilities as high as those of the average incumbent worker. In ·ce, then, the PILE has potential relevance as a measure of ·ent lifting capacity, or the ability to predict a subject's ca- ty to tolerate strenuous lifting throughout a day. It cannot be ·med, however, that the test is sufficient to permit disqualifi- ·n of the applicants or to predict LBP incidents. The potential ·ance of the PILE for frequent lifting is not shared by any iso- ic or isokinetic protocols yet established. Obviously, research ·boration through prospective studies is necessary to validate PILE utility for these purposes.

Subjects. Sixty-two men (mean age, 29 +/− 9 years; weight, 8 +/− 26 pounds; height, 69 +/− 3.8 inches) and 31 women an age, 27.3 +/− 7 years; weight, 133.2 +/− 18 pounds; height 2 +/− 3.1 inches) represented the normative sample. They sisted of a mixed blue- and white-collar industrial population.

Procedures. Each subject underwent PILE testing in both lumbar and cervical protocols, after calculation of target heart rate R; 85% of age-related maximum heart rate). Height, weight, age were recorded in order to ascertain ideal normalizing factors in this first part of the study. In order to evaluate the effects of r- and underweight, an ideal body weight (IW) was assigned. IW was obtained from the "Broad Frame" category of a standardized ideal height-weight chart.[10] Use of this category in the rt essentially assigns a weight to the patient based on height ble 1). Overweight individuals will thus have a lower IW than y weight (BW), and slim individuals will have a higher IW than ual BW.

A third normalizing weight, termed the adjusted weight (AW), was calculated. This reflected our empirical observation that malization might be skewed by overweight, but not by underght; thus, the adjusted weight (AW) utilizes the actual body ght in slim individuals, but the ideal weight in overweight individuals expressed as a formula:

$$\text{If IW} > \text{BW, then AW} = \text{BW} \quad (5)$$

$$\text{If IW} < \text{BW, then AW} = \text{IW} \quad (6)$$

Statistical analysis consisted of comparing PILE results (maximum weight lifted, endurance time, final heart rate, work/power output) against potential normalizing factors (height, weight, IW, age, Davenport Index). Means and standard deviations for measured and normalized values were calculated.

A test-retest replication study involving ten men also was performed in order to demonstrate reproducibility of results in the same subject at different times. Results of the second PILE test were correlated with the first. Repeated tests were performed on preceding days.

RESULTS

Table 2 presents the linear regression correlation coefficients for the scatter plots produced comparing lumbar and cervical final force vs. the three competing weight measures (BW, IW, and AW).

Table 1. Ideal Weights (Chart Weights) for Males and Females*

Height (in)	Weight (lbs)
Weights for women	
58	111
59	114
60	117
61	120
62	124
63	126
64	129
65	134
66	137
67	141
68	145
69	149
70	154
71	159
72	163
Weights for men	
62	144
63	147
64	150
65	154
66	157
67	162
68	167
69	171
70	175
71	180
72	185
73	190
74	195
75	200
76	205

*Measurements taken without shoes in normal indoor clothing.[10]

Values were obtained for men only because of the larger sample size and more consistent strength output. Other normalizing factors (height, age, Davenport Index) showed lower correlations. Statistical analysis included correction of scale variability to optimize selection of ideal normalization variables. In this sample, while age was not found to be a useful normalizing factor, the sample did not include a sufficiently wide distribution to draw conclusions about declining performance beyond the fourth decade.

Table 2. Regression Coefficients for AW, IW, and BW

	Males		
	BW	IW	AW
Lumbar force			
r	.31	.38	.45
Significance level	.01	.002	.0002
Lumbar total work			
r	.31	.39	.46
Significance level	.01	.001	.001
Cervical force			
r	.36	.38	.51
Significance level	.003	.002	.0001
Cervical total work			
r	.33	.39	.49
Significance level	.009	.001	.0001

*BW = body weight; IW = ideal weight; AW = adjusted weight.

Table 3. Normative Data

	AW	LW/AW	LTW/AW	CERF/AW	CERTW/AW
	Males (n = 61)				
Means	161.3	.50	22.8	.40	12.3
Standard deviations	19.6	.10	7.8	.10	5.1
Standard error of the mean	2.51	.01	1.0	.01	.81
	Females (n = 31)				
Means	121.6	.35	17.04	.25	7.32
Standard deviations	10.65	.07	7.0	.04	2.4
Standard error of the mean	1.98	.01	1.3	.01	.56

L = lumbar; CER = cervical; TW = total work in lb-ft; AW = adjusted weight in lbs; F = final force in lbs.

Based on the results shown, AW was selected as the most appropriate normalizing factor for intersubject comparisons. Following this, norms were calculated for final force and total work, using the AW correction for both men and women in lumbar and cervical protocols (Table 3). The group mean values were used subsequently in testing the "percent normal" of the patient population. In the course of the normative testing, all of the subjects discontinued testing at the psychophysical end-point; there were no aerobic or safety end-points reached for any of the normal subjects.

Test-Retest Reliability of the PILE

Correlation coefficients for the reproducibility study were $r = 0.87$, $P < 0.001$ for lumbar force, and $r = 0.93$, $P < 0.001$ for cervical force. This suggests adequate test-retest reliability for the PILE.

DISCUSSION

The present study describes a new dynamic test (PILE) for which adjusted weight was found to be the optimal normalizing factor. Previous studies had shown that lean body weight, as determined by body fat caliper measurements, offered no significant advantage over BW as a normalizing factor for isolated sagittal isokinetic trunk strength.[39] It was subsequently noted empirically that mildly overweight subjects appear to be stronger on a variety of trunk strength tests, but moderately and severely overweight individuals became proportionately less strong in relation to their actual BW as obesity increased. By contrast, leaner individuals are the only somatotype likely to reach the safety end-point on PILE testing. The statistical verification that AW should be the prime normalizing factor for PILE strength tests supports the previous clinical observations, but it will require a larger normative database to devise a formula for very lean, obese, or older workers.

A limitation of the PILE test effort factor is the absence of a dependable heart rate end-point when rate-limiting drugs (eg, beta blockers) are being taken by the subject. In cases where the rate-response is physiologically altered, testing limits must rely either on psychophysical or safety end-points. This is an important drawback and suggests the necessity of performing isokinetic tests (even for baseline screening) on these individuals. For other subjects, however, baseline screening with the PILE may be warranted, particularly in cases of industrial incumbent workers in the field or at a distance from established assessment centers.

Another drawback to the PILE (and all lifting tests) is the ina ity to discriminate the "weak link" anywhere along the biomech ical lifting chain. Thus, patients with weak trunk musculature r select the dynamic lifting style (including spinal posture and b position) that allows safest maximal lifting forces to be exer Safety is individually monitored by sensorimotor feedback me anisms, often causing the patient with LBP to maintain the b in a vertical position and use a squat to provide the lifting po In this way, in many cases, well motivated LBP patients may p duce high dynamic lifting forces when more sophisticated isola tests of spine function (trunk mobility, sagittal strength, rota strength) identify significant functional deficits. Interestingly, n healthy workers and functionally restored patients who have b encouraged to "self-select" the lifting style they perceive produ maximum safety and efficiency will generally use a methodol producing both bent knees and a bent back with the spine in su cient flexion. This will allow some of the forces to be transmi passively through the posterolateral ligamentous complex.

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Progressive Isoinertial Lifting Evaluation
Erratum Notice

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IT HAS COME TO OUR attention that there is an error in the Methods section of our article entitled, *"Progressive Isoinertial Lifting Evaluation I: A Standardized Protocol and Normative Database,"* (SPINE 13:993–997, 1988).[1] This error appears on page 994 of the article. The sentences appearing in paragraph 2 of this page: "Weight is incremented upwards at a rate equal to the initial free weight . . . every 20 seconds, with a rate of four lifting movements in each 20-second interval . . . The test is terminated when the first of the following end-points is achieved. . . ." should be replaced with the following:

> "Weight is incremented upwards at a rate equal to the initial free weight (ie, 5 pounds for women, 10 pounds for men) every 20 seconds, with a rate of *eight* lifting movements (4 lifting cycles) in each 20-second interval (Figure 1.) A lifting movement involves a single transfer from one level to the next, ie, from floor to waist (0–30 inches) or waist to shoulder (30–54 inches). A lifting cycle involves two lifting movements to return to the starting point; ie, from floor to waist to floor, or waist to shoulder to waist. Lifting progresses in sequence, floor to waist to floor, until the patient reaches the first of the following end-points:

Both normative and patient data were collected using this protocol, and are accurately portrayed in Parts I and II of the PILE papers. Unfortunately, this error also carried over into some of the calculations presented later in the **Methods** section. Data for maximum weight lifted (Final Force), Endurance Time, and final heart rate are unchanged. However, calculations for Total Work (TW) and Total Power (TP) are in error because the distance-travelled parameter (distance travelled in 20 seconds based on 4 "lifting cycles" rather than 4 "lifting movements"), was stated incorrectly in the article. For a Lumbar test, the distance travelled every 20 seconds is 2.5 feet × 8 = 20 feet, *not* 10 feet as originally presented. Similarly, the distance travelled in 20 seconds for the Cervical tests is 2 feet × 8 = 16 feet, *not* 8 feet as originally presented. Therefore, both Work and Power values are *double* those shown in the original calculation. In the example shown in the text, if a female subject reaches an end-point after completing 100 seconds of lumbar testing, she will have a Final Force of 28 pounds (the weight lifted in the final 20 seconds). She will have performed Total Work on Lumbar PILE, which is calculated as follows:

$$TW = [8 + 13 + 18 + 23 + 28] \times 20 = 1{,}800 \text{ lb-ft} \quad (1)$$

Total Power consumption (TP) is the work performed divided by the unit of time and is represented:

$$TP = TW/t = 1{,}800 \text{ lb-ft/100 sec} = 18 \text{ lb-ft/sec or } 24.8 \text{ Watts} \quad (2)$$

In addition, if the same subject performs the Cervical tests in identical fashion (but with distance travelled per 20 seconds being 16 rather than 20 feet) then:

$$TW = [8 + 13 + 18 + 23 + 28] \times 16 = 1{,}440 \text{ lb-ft} \quad (3)$$

$$TP = 1{,}440 \text{ lb-ft/100 sec} = 14.4 \text{ lb/ft/sec or } 19.8 \text{ Watts} \quad (4)$$

Based on the calculation error, the Normative Data presented in Table 3 for Total Work to Adjusted Weight (TW/AW) will be doubled in each instance. The corrected mean scores are as follows:

Corrections to Table 3: Normative Data

Males:	Lumbar TW/AW	45.6 lb-ft/lb
	Cervical TW/AW	24.6
Females:	Lumbar TW/AW	34.1
	Cervical TW/AW	14.6

In the PILE II study (*Progressive Isoinertial Lifting Evaluation II. A Comparison with Isokinetic Lifting in a Disabled Chronic Low-Back Pain Industrial Population*),[2] Table 2 presents patient data, which includes male/female TW/AW ratios for lumbar and cervical tests on admission and discharge from a functional restoration program. In each instance, the TW/AW mean value must be doubled. However, ratios and percent normal (as presented in Figures 1–3) are unchanged. These values are unlikely to be used by other research groups interested in replicating the tests and utilizing the norms, and therefore will not be recalculated.

The authors wish to stress that the test itself was implemented in a consistent fashion with accurate data collection and analysis. Other data and conclusions presented in the studies represent actual observations and are unaffected by the calculation errors introduced by the erroneously drafted protocol. The authors wish to apologize for any inconvenience produced to readers using this protocol. We hope that the published Errata will result in appropriate test implementation.

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